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No 496 **1959** **JAN.—FEBR.**

GEOLOGISKA FÖRENINGENS

I STOCKHOLM

FÖRHANDLINGAR

UTGIVARE

PER H. LUNDEGÅRDH

BAND 81 **HÄFTE 1**

Edited by the Geological Society of Stockholm
Stockholm 50
Subscription by Nordiska Bokhandeln, Stockholm 1

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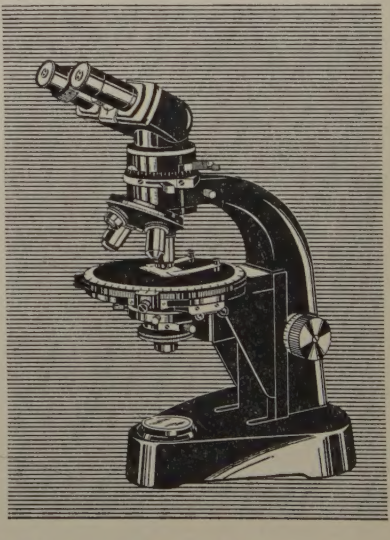

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Större tabeller bör vara skrivna på särskilt papper och skall vara numrerade med romerska siffror. De skall dessutom vara försedda med rubrik, som klart anger inne-

1. *Orätt bokstav.* Drag ett streck genom bokstaven.
Upprepa strecket i marginalen och skriv där bredvid den
rätta lokstaven. |b
2. *Orätt ord.* Drag ett streck genom första och sista bok-
stäverna och förena dem med ett vågrätt streck, varmed ordet
genomstrykes. Upprepa hela detta tecken i marginalen och
skriv där bredvid det ~~fiktiga~~ ordet. H rätta
3. *Utelämnad bokstav.* Markera det ställe, där boksta-
ven skall stå, med ett noga inpassat S-böjt streck. Upprepa
detta i maginalen och tillfoga där den felande bokstaven. Ett r
annat sätt är att draga ett streck genom en närstående bok-
stav och skriva båda bokstäverna efer ett likadant streck i |ft
marginalen.
4. *Utelämnat ord.* Drag ett streck, där ordet saknas.
Skriv felande ordet efter ett likadant streck i marginalen. det (Se nedan)
5. *Omkastade bokstäver.* Skola två närstående bokstäver
byta plats, omslutas de med omkastningstecknet ∽, som
upperpas i marginalen. Vid annan omflyttning inom ett ord ∽
behandlas detta såsom ett orätt ord enligt ~~pkunt~~ 2. H punkt
6. *Omkastade ord.* Om två närstående ord i samma rad
skola plats byta, användes omkastningstecken som i punkt 5. ∽
Annan omflyttning av ord kan markeras genom numrering,
som i marginalen upprepas, eller också enligt punkt 7. 1 2 3
7. *Flyttning till annan rad.* Drag en ring runt det ord,
som skall flyttas, och ange med ett från ringen utgående
pilstreck, var ordet skall stå. I marginalen göres ett liknande
tecken.
9. *Flyttning av hela rader eller stycken.* Markera ra-
derna med en klammer i marginalen och låt ett från klam-
mern utgående pilstreck visa, vart de skola flyttas. Med pil-
streck kan man också markera flyttning av rubriker m. m.
8. *Omkastade rader* numreras i marginalen eller be-
annat än när texten är satt på radgjutningsmaskin.) 2
handlas enligt punkt 9. (Fel av detta slag bruka ej uppkomma 1
10. *Borttagning.* Bokstäver, ord ellerr rader, som skola |₰
försvinna, markeras med streck enligt punkterna 1 eller 2.
Efter motsvarande tecken i marginalen utsättes tecknet ₰,
delea'tur (= borttages). (Att ett eller flera ord av misstag
~~misstag~~ upprepats kallas »bröllop».) H₰
11. *Upp- och nedvänd bokstav.* Drag ett streck genom
bokstaʌen. Upprepa strecket i marginalen och utsätt där |√
bredvid tecknet √, *verta'tur* (= vändes). (Detta fel kan
ej förekomma, när texten är satt på radgjutningsmaskin.)

(Att ett eller flera ord av misstag utelämnats
kallas "lik".)

12. *Orätt typsort.* Drag ett streck genom bokstaven. Efter samma tecken i marginalen utskrives bokstaven på nytt inom en ring. D

13. *Trasiga typer* anmärkas liksom i punkt 12. g p

14. Ändring av typsort. Stryk under det ord, som skall omsättas med andra typer. Anteckna inom en ring i marginalen den önskade typsorten (t. ex. kursiv eller halvfet). kursiv

15. *Spärrning.* Stryk under det ord, som skall spärras, och skriv ordet spärras inom en ring i marginalen. spärras

16. *För stort ordmellanrum.* | Drag ett streck i mellanrummet. Upprepa strecket i marginalen och utsätt där bredvid sammandragningstecknet ◡.

17. *För litet ordmellanrum* anmärkes liksom i punkt 16 men med åtskillnadstecknet ⌒.

18. *För stort eller för litet radmellanrum.* Drag mellan raderna ett vågrätt streck ut i marginalen och tillfoga där sammandragningstecknet ◡ eller åtskillnadstecknet ⌒.

19. *Nytt stycke.* Gör tecknet ⌐, där det nya stycket skall börja, samt i marginalen. 20. *Sammandragning av två stycken.* Drag en böjd linje från slutet av det ena stycket till början av det andra. Teckna en liknande linje i marginalen.

21. *In- eller utdragning.* Om en rad börjar eller slutar på oriktigt avstånd från textens sidokant, anbringas en hake, ⊐ eller ⊏, med ryggen intill det ord som skall flyttas. ⊐ Haken drages ut så långt, att den visar, vart flyttningen skall ske, och upprepas i marginalen. (Se även punkt 9.)

22. *Krokig rad.* Om vissa bokstäver ej stå på linje, anmärkes detta med två vågräta streck, ett över och ett under raden. Strecken upprepas i marginalen.

23. *Ojämn sidokant.* Drag två parallella linjer i marginalen. (I spaltkorrektur är sådan rättelse onödig, enär de lösa raderna komma i rätt läge vid textens ombrytning till sidor.)

24. *Spis.* Därmed förstås avtryck av en utslutning eller reglett, som stigit upp så att den nått papperet. Drag ett streck över spisen, upprepa det i marginalen och tillfoga där ett dubbelkors #. Ett liknande avtryck uppkommer, när en typ blivit satt med foten uppåt. Ett sådant fel anmärkes liksom en orätt bokstav enligt punkt 1. # # g

25. *Återtagning.* Om man finner, att en gjord rättelse ej skall utföras, ~~öve~~rstrykes vad som skrivits i marginalen, och det rättade stället i texten underprickas.

hållet. Samma data får i allmänhet ej framläggas på mer än ett sätt: tabeller eller diagram. I samtliga avhandlingar skall i förekommande fall *decimalpunkt* användas (även betr. publikationer på skandinaviskt språk).

Figurer skall vara numrerade med arabiska siffror och ha utförlig text, bl. a. upptagande förklaringar till i figurerna förekommande bokstavsbeteckningar o. d. Fotografier skall vara kontrastrika och gjorda på blankt papper. Ritningar skall utföras med svart tusch på hållbart, ljust papper och ha jämna, snygga linjer. Maskinskrift på ritningar är förbjuden. Text till samtliga figurer och illustrationer sammanförs på särskilt papper.

Författare kan i manuskriptet utmärka de delar av arbetet, som skall sättas med mindre stil, redaktionen dock obetaget att härvidlag göra ändringar enligt av SGU eller GFF tillämpad praxis.

Kursivstil används för latinska namn. Spärrad stil brukas undantagsvis för att framhäva vissa ord eller meningar i texten.

I manuskriptet utmärks

kursiv med ————

spärrning med - - - - - - - -

KAPITÄLER med ═════ (används icke för författarnamn i löpande text)

Halvfet med ~~~~~~~~ under de ord som avses.

Vid ändring i korrektur används gängse tecken enligt ovanstående mall (sid. 2—3).

Litteraturhänvisningar anförs i texten med angivande av författarnamn och arbetets tryckår inom parentes: (Sahama 1954). Sida i det citerade arbetet utsätts vid behov (Sahama 1954, p. 23).

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BGIU = Bulletin of the Geological Institution of Upsala
GFF = Geologiska Föreningens i Stockholm Förhandlingar
KVA = Kungl. Vetenskapsakademien
SGU = Sveriges geologiska undersökning
DGU = Danmarks geologiske undersøgelse
MDGF = Meddelelser fra Dansk geologisk forening
NGT = Norsk geologisk tidsskrift
NGU = Norges geologiske undersökelse
Bull.géol.Finl. = Bulletin de la Commission géologique de Finlande.

I övrigt begagnas internationella beteckningar.

Beträffande användandet av typer och skiljetecken i litteraturförteckningen hänvisas till följande exempel. Här sätts författarnamnen med kapitäler.

KARLSSON, I. G., 1957: Banded gneisses and granitization. — GFF 79.

LUNDQVIST, G., 1957: C 14-analyser i svensk kvartärgeologi. — SGU, C 557.

Förkortningar. Följande detaljer bör uppmärksammas:

km m dm cm mm (antikva utan punkt; observera, att m.m. betyder med mera)

dr (doktor), prof. (professor), hr (herr).

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GEOLOGISKA FÖRENINGENS
I STOCKHOLM FÖRHANDLINGAR

No 496

Band 81. Häfte 1. Jan.—Febr. 1959

Outline of Mineralization in Zoned Granitic Pegmatites

A Qualitative and Comparative Study

By

O. Brotzen

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Abstract

An introduction to the general problems and procedures of the paper is given, and the background and approach are indicated. Zoned granitic pegmatites are divided into four groups with respect to major constituents. Simple pegmatites, composed mainly of biotite, plagioclase, microcline, and quartz, are distinguished from more complex ones with muscovite, late albite, and lithium minerals respectively. Two types of internal zoning are recognized. They differ in the nature of outer zones, which are made up of granite and graphic granite in one pattern, and of quartz and quartz-muscovite assemblages in the other. The first type is preferentially developed in simple pegmatites, and the other one in more complex deposits. Outer zones of the second type pattern mineralogically resemble inner zones, especially the quartz core and its margin, and therefore this pattern is considered to be reversed, and the pattern of simple pegmatites is chosen as a basis for the later discussion. It is shown that pegmatites crystallized from the walls inward and that internal zoning developed rapidly, and not in response to secular changes in geologic conditions. Internal spatial zones are not accepted as strictly synchronous or paragenetic formations. The following main paragenetical groups are recognized instead: the granitoid, the graphic granite, and the pegmatoid zones, the core margin, alkali replacement, and core margin mica groups, and the quartz core and late alterations. A schematic two-dimensional synopsis of mineralization in pegmatites is given, showing the correlation of minerals with development of pegmatites and paragenetical groups within these. Some features of wall rock alteration and of primary pegmatitic cavities are presented.

In the discussion specific genetical problems of pegmatites are indicated, especially those involved in the strong geochemical fractionation, and the formation of the pegmatitic texture, the quartz core, and alkali replacements. For geological reasons a magmatic approach is chosen as a starting point, since it is valid for at least some pegmatites. Claims of a general harmony between mineral association in pegmatites and degree of metamorphism in the surrounding region are rejected and it is shown that they are based on insufficient data and mistakes in reasoning.

Interpretation is started with deductions of temperatures, pressures, and gross composition of pegmatite systems. Pegmatitic crystallization is explained as a consequence of low magmatic temperatures, which imply low energy-content and poor nucleation in pegmatite systems. Fractional crystallization is thus the result of heat — and concentration gradients towards the walls and scarcity of growth centres. It is essentially non-eutectic. Scarcity of growth-centres is also the cause of the formation of giant crystals, crystal size being expressed as the mass of crystallized matter divided by the number of available growth centres.

Crystallization of quartz is shown to be abnormal by the stop in the formation of graphic granite and the subsequent late formation of the core. After exclusion of alternatives it is explained as being caused by immobilisation of silica due to increased activity of CO_2. Muscovite marks increased activity of H_2O and CO_2, i. e. hydration and extraction of potassium and silica. Alkali replacements are caused by supersaturation (sugary albite) and by changes in stability relations upon the appearance of an aqueous, carbonated phase (cleavelandite, spodumene, petalite), i. e. increased activity of H_2O and CO_2 and an excess of alkalies over the amount necessary to balance Al_2O_3. Interpretation is extended to explain reversed (American) zoning and the occurrence of minor minerals. Outer zones rich in quartz and muscovite denote an originally high content of H_2O and CO_2 whereas the distribution of minor minerals reveals the influence of the same fundamental factors, which ruled the occurrence of major constituents. A special factor is the inactivation and precipitation of core-silica, which raises the concentration of rare constituents in the residual system and favours precipitation of compounds with other anions in the core margin.

For a general background brief statements on the mechanisms of the chemical differentiation of pegmatites, and their magmatic and metamorphic genesis are given, along with some comments on the structural behaviour of pegmatites, its relation to metamorphism, and some indications of analogies with other types of rocks and mineral deposits.

Introduction

Preface

Mineral formation from silicate melts approximating natural rocks is by now rather well understood and has been studied in Nature as well as by experiment and theory. The same may be said of crystallization from dilute aqueous solutions. Mineral formation in the vast physicochemical field between these two extremes is, however, still largely unknown. This is the more unfortunate as a great number of special fractionations, concentrations, and accumulations, often leading to mineral deposits of great theoretical and practical value, are generally assumed to occur in this field.

Attempts to approach this field from the magmatic, Bowen (1933), Fenner (1931—1940), Niggli (1920, 1937), Vogt (1926), as well as from the hydrothermal side, Graton (1940), Ross (1933), have been made. So far conclusions have been incompatible with each other, and discussion temporarily ceased while additional physicochemical data were awaited.

In spite of a steady accumulation of such data from pertinent systems the general situation has not become much brighter than it was two or three decades ago. This is largely due to difficulties in the application of the data to natural phenomena, which in turn is partially due to the widening gap between experimenters and theoreticians on one side and geological observers on the other side. The former, even with more than a good textbook knowledge of geology often will be unfamiliar with geological technique of observation and deduction. He will probably feel disorientated by the complex and controversial nature of primary geological information and he will, to some extent, loose confidence in it and prefer a highly schematic presentation. The geologist, even with a good knowledge of physicochemical and geochemical theory, often finds that the results of experiments are far too simple to be applicable to his actual complex reality, and further that they often are based on inadequate premises. The factual difference, however, is one of approach and is determined by the nature of the objects.

Experiments usually are devised to study the influence of only one variable at a time, and disturbances are kept at a minimum and are further reduced by repetition of experiments. In Nature's experiments variables are complex and disturbances important and often nonstatistical. Therefore, in many instances, ideal cases must first be deduced from observations before a solution of their genetical problems can be found. This may be likened to the deduction of an ideal crystal lattice from a crop of highly imperfect individuals.

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The procedures used to this end by the geologist often seem to the experimenter difficult to understand and accept. It must be remembered that imperfections in natural, complex objects often are of nearly the same order of magnitude as regular features. This makes a statistical approach futile. One procedure therefore is to identify and select for further consideration a limited number of most nearly perfect individuals. This is not a statistical problem, or the same as identifying the majority case or a representative average. Even if the rôle of personal judgement (subjective factors) in such a procedure is evident, it can hardly be denied that it may yield useful information on characteristic and significant parameters. These may, once they are identified, in a varying degree also be recognized in the rest of the population. Clearly a knowledge of the population is essential for making a representative selection along these lines. Much of the controversial nature of geological information ? is not due to the general shortcomings of such a procedure, but to the extreme variation in natural populations. If however, discussions and interpretation are again made with direct reference to the actual cases thus chosen, validity of results is at least retained in this restricted sense, even if generalization on the entire group should be in error.

The following paper is an attempt to bridge the gap between experimenters and field geologists from the field-geologist's side regarding the special case of zoned granitic pegmatites, and the discussion above was presented in order to illustrate and make acceptable the procedures which have been followed.

Zoned pegmatites generally are believed to represent conditions near the lower limit of the magmatic field or transitions to hydrothermal conditions, and because of this they also are of a more general interest. As a group they show highly specialized features of texture, mineralogy, and geochemistry. A number of general trends of their geochemistry has been recognized, but in spite of many attemps their detailed evolution and mineralization have resisted interpretation even in outline. In the writer's opinion the difficulty is largely of the type indicated above, theoreticians have started with a too simple and schematic notion of the subject. It is believed to be necessary to consider each step of mineralization separately and also in relation to the evolution of the entire mineral deposit.

In order to do this, granitic pegmatites have been analyzed paragenetically, different deposits have been compared and analogous paragenetical groups have been recognized. This has been done qualitatively, which seemed to correspond to the present status of the problem. A quantitative approach would have been premature before the qualitative analysis had been accomplished. It is hoped that this analysis will prove of value in discussions of pegmatite genesis, even if it is realized that no one individual can master this entire subject, and errors both in observation and generalization may occur in the following presentation.

Interpretation, on the other hand, has been made to the best of the writer's knowledge and imaginative power, but, as the approach is essentially that of a field-geologist it is feared that physicochemical reasoning may be awkward in places. It is furthermore possible that interpretation should have started from other basic assumptions and proceeded along other lines of thought. Alternative interpretations, as well as discussion on inherent observations and generalization are herewith invited. It is nevertheless felt that the complex, yet orderly, sequence of mineralizations in zoned granitic pegmatites provides a set of limiting conditions, which can only be satisfied by a very limited number of solutions. Even if the present interpretation should turn out to be partially or entirely incorrect it is hoped that it may serve as an indication of the stepwise interpretation, which is required by composite and complex types of mineral deposits.

Earlier Work

An excellent survey of earlier work on pegmatites together with a synthesis of recent knowledge and interpretation has been given by Jahns (1955) and the interested reader should consult that extremely valuable reference. Before entering a discussion of recent trends, it may, however, be worth while to consider briefly the observational data which underlie the views developed by some of the most influential leaders in the study of granitic pegmatites.

W. C. Brögger (1881, 1906, 1922) investigated the granite pegmatites of Southern Norway, which are mined for feldspar and quartz, and are occasionally rich in accessory minerals such as tourmaline, beryl, fluorite, and niobates, tantalates, phosphates, and silicates of the rare-earth metals. Li-minerals, in contrast, are systematically absent, and replacement features in general are rare.

A. E. Fersman (1931) had an enormous knowledge of granite pegmatites, having seen a great number of Russian and European occurrences, for instance in Southern Scandinavia, on the Isle of Elba, in the Urals and Siberia, furthermore, he seems to have penetrated all the essential literature of his time on pegmatites. The emphasis of his own work seems to have been on gem pegmatites of Russia, such as those of Mursinka and Adoun-Tchoulong.

The American school of 1925—1940, headed by F. L. HESS, K. K. LANDES, and W. T. SCHALLER, studied a variety of pegmatites, but, in great simplification, it may be stated that the main interest centered around Li-mineralizations and related phases where replacement is a most important process.

In a similar way it may be said that recent interest in granite pegmatites in the U. S. A. arose from wartime need of domestic sources of mica, Nb, Ta, Sn, Be, U, and Li, and consequently features exhibited by pegmatite deposits of these mineralizations together with an increasing amount of laboratory work dominate recent thought on the subject.

Finally, observations in metamorphic terrains, especially on migmatite-veins and minor pegmatites (few if any pegmatitic mineral deposits being considered) in conjunction with theoretical considerations seem to be the basis for opinions as voiced b H. RAMBERG (1949, 1956).

Turning now to recent interpretations of pegmatites, we find that JAHNS, loc.cit., with a wide personal experience of a type indicated above, and after surveying most of the pertinent literature, arrives at the following conclusions, as stated in his abstract: "In this writer's opinion, all the observed features of numerous pegmatite bodies, especially those of complex mineralogy, are most readily explained by a combination of two processes: (1) progressive crystallization of segregated or injected restmagma under restricted-system conditions, accompanied by some reaction between the crystalline phase and the residual liquid, and (2) resurgent boiling of the residual liquid, condensation of the vapor at points within the pegmatite system, and partial (commonly selective) replacement of the crystalline phase by the condensate".

More specifically it is found in the text that pegmatites were emplaced as magmas or magma-like fluids, the composition of which is described as silicate and alumosilicate systems, not differing much from that of ordinary igneous rock, but with volatile constituents; water, carbon dioxide, boron, chlorine, fluorine, and phosphorus (compounds) being named. The compositional differences between pegmatites and ordinary igneous rocks lie mainly in the distribution of minor elements. Crystallization, according to modern views, took place in a resticted system, and the order of crystallization in pegmatites is in accordance with the reaction principle of Bowen, or logical extensions of this. Abnormal features, incompatible with this view, but of widespread occurrence, such as quartz-cores or various replacement sequences, are explained as products of resurgent boiling within the system and fractional distillation of volatiles. The bulk of mineral matter in most types of pegmatite was formed in the temperature range of 700°—250° C, and most internally zoned bodies of pegmatite probably began to crystallize at temperatures not greatly in excess of about 550° C.

It may be interesting to compare these conclusions with the views held by FERSMAN (1931). It is found that, a quarter of a century ago, he had arrived at the very same conclusions. Thus he had already at that time formulated the conditions of a restricted system, the type-composition of the granite pegmatite magma, the conformance with, and extension of, Bowen's reaction series, the rôle of resurgent boiling (as outlined by Niggli) and fractional distillation, and he had derived exactly the same temperature-range of pegmatite-formation. In addition, Fersman gives a diagram of the order of crystallization of pegmatite-minerals, realizing both that a mineral may have a certain range (sometimes fairly wide), and may vary in habit and appearance, and for those cases both range and modifications are indicated in his tables. He also points out that these »geochemical» tables are of a statistical nature and only indicate the most frequent sequence, and he enumerates some of the factors which might cause a displacement in the diagram. On the basis of these tables Fersman also is able to give a differentiation sequence of granite pegmatite types, this forming his classification. In a later publication, summarized in French by VARLAMOFF (1946), Fersman demonstrates the arrangement of the differentiates in geologic space. All this, together with a wealth of observations and reflections on genesis and geochemistry, makes Fersman's work, to the knowledge of the present writer, in many respects the most advanced treatise on granitic pegmatites, in spite of notable achievements of a more recent date in the U. S. A. and U. S. S. R.

Fersman's work has found wide acceptance, and his concepts have been successfully applied in many pegmatite districts. Thus VARLAMOFF (1954) reports on very recent applications in the Belgian Congo and Ruanda-Urundi, cf., however, SAFIANNIKOFF (1955), and he also delivers a very illuminating discussion on the relations between Fersman's work and the stand of the modern American school of students of pegmatites.

As a matter of fact, Fersman's work has recieved a minimum of attention in the U. S. A. This may be due to linguistic difficulties and the fact that Fersman, in spite of reporting on the internal zoning of pegmatites, did not especially emphasize these features. Perhaps also Fersman's treatment of those pegmatite types in the centre of American interest is the least satisfactory part of his work, as indicated above.

It is only fair to note that recent development in Russia also seems to swing away from Fersman. Thus ZAVARITSKY evidently works with an open system model and much metasomatism, whereas VLASOV (1955) objects to Fersman's conclusion that rare metal granite pegmatites are formed from a residual (rest) magma and instead he suggests that they are products of an emanation (distillation) process. Again it should be noted that Vlasov's main arguments are derived from the investigation of Li-pegmatites and related types.

Facing these adverse reactions in various parties, it seems necessary to analyze which are the weak points in Fersman's elaborate system. It seems evident to the present writer that the difficulties cannot be avoided just by correcting Fersman's representation of relations in Li-pegmatites, but that the shortcomings are of a more fundamental nature. This may also explain the attitude taken by Vlasov.

Fersman's working method involved two major steps, 1) the establishment of the order of crystallization from studies in the field and many thousands of specimens, 2) the correlation of the results with the theoretical concepts of physical chemistry of his time, notably as outlined by Niggli, Vogt, Morey, and Bowen.

From the second step Fersman's theory inherited all the shortcomings which may afflict those fundaments. However, the main substance of his work is in his observations on genetical sequences, and this part, through his own work, was carried almost to completion, leaving only minor corrections and additions to be made by later students. By choosing the order of crystallization, that is relative time, or in his own setting, decreasing temperature, for the basis of his system, this factor becomes the sole independent variable, which is, however, insufficient for a complete understanding of granite pegmatites. From Fersman's own writing it is definitely evident that he was well aware of the rôle played by other, independent, factors, but these could not be accounted for in his system of representation. Therefore, in order to advance further, it seems necessary partially to dispose of his system, but, naturally, the deep insight derived from it must be included in all future work on these problems.

General Background of the Present Approach

Before outlining the present approach it may be appropiate to indicate briefly the type and extent of underlying observations, as was done in a general sense at the outset of the previous section.

The main basis of the following paper consists essentially of direct field observations from various pegmatite districts. Thus the writer (1945—47) has investigated granite pegmatites in the area around *Stockholm, Sweden,* where simple pegmatites are found in very great number and excellent exposures. At the periphery of that area are also found more complex types, among others the famous deposits of *Ytterby* (NORDENSKJÖLD 1908; minerals of Y, Ce, Nb, Ta, Be), *Utö* (SUNDIUS 1952; spodumene, petalite, amblygonite, tourmaline, beryl, and cleavelandite), and *Norrö* (ERIKSSON 1946; muscovite, beryl, albite, triphyline, and arrojadite).

Another investigation (1950—52) dealt with pegmatite deposits in *Southwestern Sweden,* where a wide range of pegmatites, from fairly basic types with oligoclase, amphibole, biotite, and quartz (*Derome, Halland*) over intermediate ones, with two micas and some beryl (*Brattås, Orust*) and those mined solely for muscovite (*Orust*) to rather extreme types with cleavelandite (*Högsbo, Timmerhult*) and lepidolite (*Väne Ryr*), is represented.

A third investigation (1955) was of muscovite mines in *Northern Angola,* Portuguese West Africa.

Less detailed work, but nevertheless resulting in considerable familiarity with the subjects, was spent on granite pegmatites in *nothernmost Sweden (Norr-*

botten) and at the famous deposit of *Varuträsk* (QUENSEL 1952, 1956, and earlier), and some deposits with muscovite, tourmaline, and beryl in *Valle di Madonna, Ticino, Switzerland* (PARKER *et al.* 1939).

On excursions the writer has visited pegmatites at *Perstorp, Skrumpetorp* and others, *Östergötland*; and also around *Västervik, Småland, Sweden; Kimito* and *Tammela, Finland; Cornwall, England;* and *Eilath, Israel.* The granite pegmatites with crystal cavities at *Baveno,* northern *Italy,* have also been briefly studied.

Types of pegmatite with which the writer unfortunately has no field experience comprise, among others, gem pegmatites, tin-bearing pegmatites, and phosphate- and sulphide-rich pegmatites.

Laboratory work so far has only been aimed at determination of minerals, mostly by the optical immersion method.

Outline of Present Approach

From the work indicated above and complementary reading there emerged three observations, which underlie the fundamental concepts of the following exposition.

1) The mineralogical and textural pattern of many complex granite pegmatites from various parts of the world may be described on the basis of the simple pattern of the most simple unmineralized pegmatites of Stockholm, upon which a number of complicating features have been superimposed.

2) These complicating features are introduced by the appearing of a few, often simple, associations of minerals, which, when found, repeatedly exhibit the same very special or peculiar features.

3) Many granite pegmatites, which cannot be described in this way, may nevertheless be understood in terms of the simple pattern and complicating features, by shifting the relative rôles and the order assigned to these two themes. To this group belong many, but far from all, muscovite-producing deposits and lithium pegmatites.

The course followed, then, will be to start with a presentation of conditions as found in the Stockholm area, and thereafter proceeding by way of examples to more complex pegmatite bodies, trying at each step to characterize the additional complicating features. Finally an attempt will be made to apply the results to those types of pegmatites referred to in the third statement above.

In this way an array is deduced which in many respects resembles the one established by Fersman. However, at the outset, it is purely descriptive and based on increasing complexity only. Furthermore, instead on relying on the order of crystallization of individual minerals, which is often very difficult to establish, an attempt is made to define the succession of mineral associations, their interrelations and mineral content.

To the extent to which this is achieved it may form the basis of a discussion of the type of processes which may have been active in the formation of the various phases, and of the geochemical principles which rule the development of granite pegmatites.

Throughout the paper examples and ideas have been cited from sources with which the author happens to be familiar, and no special effort has been made to assess questions of priority or to find the earliest or most appropiate descriptions of critical features. These aspects have been largely ignored in order to save time and work. This somewhat crude practice seemed permissible, for the same aspects have been taken care of in the more exhaustive papers by Fersman and Jahns.

Factual Basis

In the following section descriptions will be given of various features and observations which are believed to be of genetical significance in relation to granitic pegmatites. Most of these have been described many times before, but it was necessary to assemble them into one body of information which might serve as a basis for the subsequent discussion and interpretation. Emphasis is laid on Swedish deposits and most examples are from deposits of which the author has a first hand knowledge. The conclusions finally suggested thus primarily refer to these occurrences, but it is believed that they may be applicable to a much larger number of similar pegmatite deposits. This, more general, applicability is indicated by short descriptive references to literature. A fuller treatment in this respect is given some occurrences which show a zonal pattern similar to that of the Stockholm pegmatites. This is done in order to give a certain documentation for the claim that this zonal pattern is a quite common and widespread feature in granite pegmatites, in spite of the fact that no attention has been given to it in some recent authoritative treatises on internal structures in granitic pegmatites, e.g. Cameron *et al.* (1949). Pegmatites of this type are often called simple pegmatites in the following text, but generally simple and complex are first used as relative terms, and not in a strictly defined sense as proposed by Landes (1933) or Rankama and Sahama (1950). In the text microcline has been used as a mineral name also when the mineral is perthitic. Likewise pegmatite is used synonymously with granitic pegmatite.

SIMPLE PEGMATITES

Pegmatites of the Stockholm Area

The bedrock of the Stockholm area has been described in detail by Sundius (1948). In short it is made up of an Archean complex of kinzigitic, granitic, dioritic, and amphibolitic gneisses, a great portion of which are migmatites. The Stockholm granite, an evengrained (mm grains) grey or red granite, intrudes this complex in a number of small and medium sized bodies. On a regional scale these bodies conform to a certain extent with the structures of the gneiss complex, as seen in outcrops, relationships are nevertheless distinctly those of crosscutting, brecciation, and stoping. Thus in most places the granite

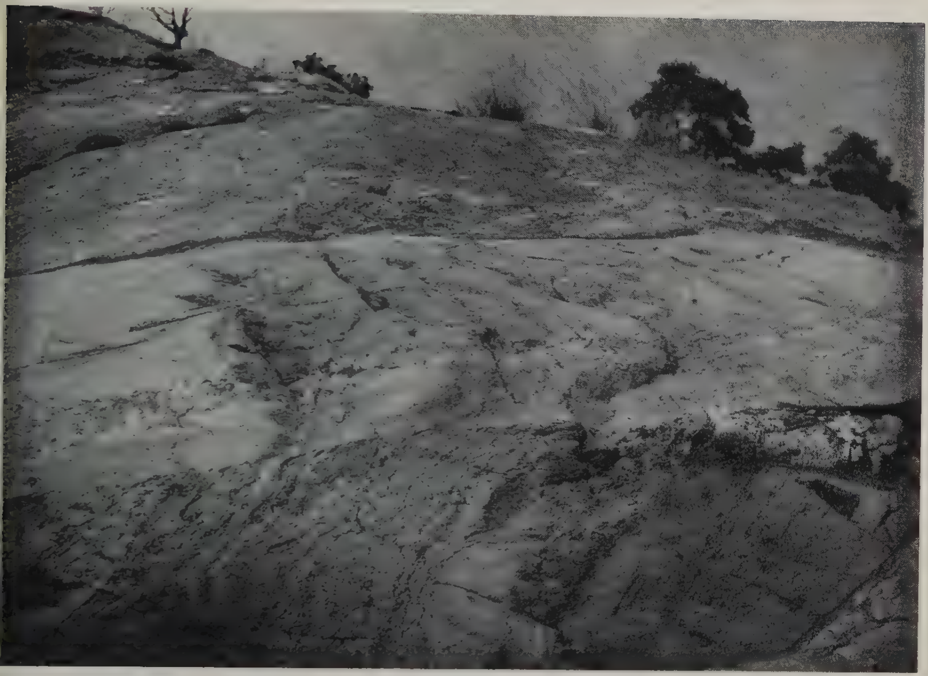

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Fig. 1. Composite dyke of Stockholm granite and pegmatite cutting through migmatitic gneiss. The pegmatite is zoned and partly without sharp boundaries against the granite. 1:50. Mörbybacken, Norrtäljevägen.

is clearly younger than the migmatitization, in some instances also gradational contacts with the wallrock may be seen. No signs of contact metamorphism around the granite bodies are present, but in the southern part of the area, xenoliths of paragneisses with reaction rims are found.

The pegmatites of the central area show considerable variation in composition, colour, structural behaviour, and relative age (as manifested by cross-cutting). As a rule the latest pegmatites are the ones showing the best developed internal zoning, the most marked dominance of potash feldspar over oligoclase, and the clearest evidence of dilational emplacement and independence of foliation in the surrounding rocks.

A small number of these pegmatites are seen to form regular parts of granite dykes, Fig. 1, or apophysae from granite bodies and demonstrating gradational transitions from granite to pegmatite. Most late pegmatites, however, are clearly a little younger than the Stockholm granite, transecting it in straight fissure dykes, cf. Fig. 2.

The most complete sequence of internal zones from the walls inward in the pegmatite bodies is as follows:

) Border zone of granitic or aplitic grain and composition i.e. microcline, plagioclase (oligoclase approx.), quartz, and biotite, grain size increasing nward.

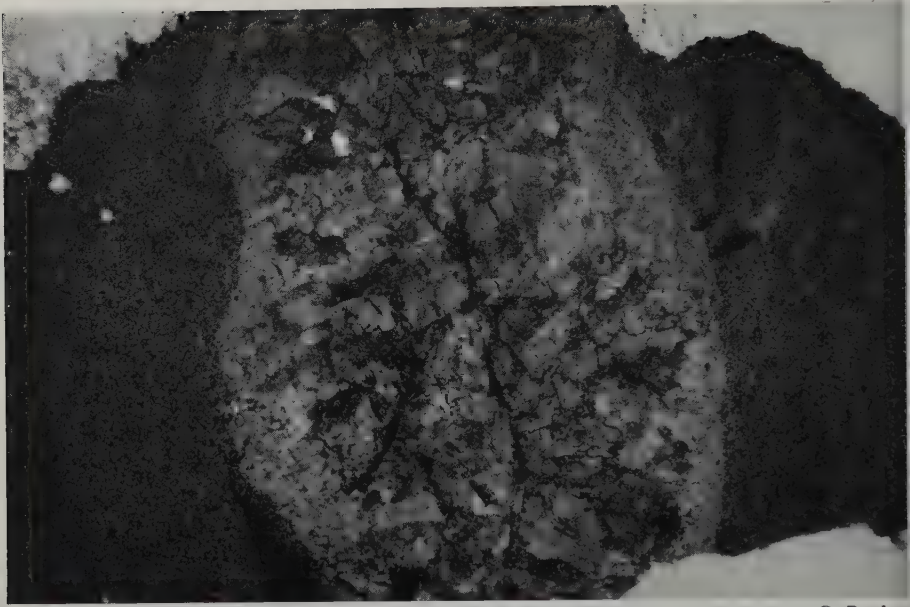

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Fig. 2. Zoned pegmatite dyke cutting through Stockholm granite. Sharp contacts, orientated feldspars, no well-defined quartz-core. (White is snow.) 1:10. Kungsholmsstrand.

2) (Wall) Zone composed of graphic granite (microcline and sometimes also oligoclase intergrown with quarz-rods), biotite is a subordinate constituent.

3) Intermediate zone of coarse blocky microcline, with biotite and sometimes oligoclase in subordinate amounts.

4) Core of quartz.

This complete sequence is seen in many individual pegmatite bodies in the area and it is the zonal arrangement chosen as the basic pattern of granitic pegmatites throughout the following exposition.

Some comments seem warranted. The graphic granite wall zone sometimes is incomplete, so that, instead of a continuous zonal shell, only isolated feldspar crystals with the typical quartz-intergrowths are found, but in that case they are arranged in a zonal manner between the border zone and the zone of block-microcline. Sometimes graphic granite seems to be lacking altogether.

The separation of the quartz-core from the microcline-zone may be more or less perfect. Often the quartz is found as a discrete core or as a series of lenticular pods near the median plane of the pegmatite-mass, but usually it also fills the interstices between microcline crystals of the intermediate zone, and sometimes microcline in the form of isolated large crystals is found floating in the core-quartz. These variations, however, do not change the general picture of zonal sequence as here suggested.

Accessory minerals are rarely found in the pegmatites of the central Stockholm area. Some of the minerals, such as graphite, sillimanite, cordierite, and amphiboles (anthophyllite and hasting sitic hornblende, cf. GEIJER (1913), may be regarded as due to contamination from kinzigitic or amphibolitic wallrocks.

Garnet is quite common, often it is completely replaced by chloritic biotite.

Allanite is perhaps the most frequent accessory mineral. It may be found in big lumps or as prismatic crystals, reaching some decimeters in length. Usually the mineral occurs as cm-sized black irregular grains.

Zircon and varieties of the type called cyrtolite or malacon are often found in mm-grains, sometimes even reaching cm-size.

Titanite is rare. It has been found in the central part of small pegmatitic veinlets which form by the mergence of leucocratic spots of the »spotted granite», cf. GEIJER (1908).

Gadolinite has been noted only twice.

Muscovite is characteristically rare, but may be found in very late-type, quartz-rich pegmatites and also in those showing signs of contemporaneous deformation.

Scapolite has been found in minor quantities in three different pegmatite bodies. Apart from this there occur independent scapolite-veins in the area, cf. GEIJER (1913).

Tourmaline has been found but once, in spite of close inspection of many hundreds of pegmatites. The one occurrence was shown to me by J. Offerberg. It was in a large pegmatite dyke, 3 m wide, transecting amphibolitic metagabbro at Hammarby. It was fairly rich in quartz and biotite, black tourmaline occurred plentifully, muscovite was present. The dyke was surrounded by a diffuse zone of biotitization.

Apatite has been found in slender green prisms, reaching 4 cm in length.

Monazite, in 1 cm-sized crystals, has been noted repeatedly in a region north of Stockholm around Ålkistan—Stocksund.

Small specks of metamict, weakly radioactive niobotantalates, poor in titanium, have been found repeatedly. Tentatively these have been called fergusonite and yttrotantalite according to colour. A number of sulphides may occasionally be found, pyrite, pyrrhotite, and molybdenite being the most frequent. The ironsulphides often are accompanied by dark chloritic ? alteration of nearby feldspar crystals.

The paragenetical relations have been summarized in a composite diagram of the type devised by Fersman, but with zonal distribution as a basis, cf. Fig. 3. From that it is evident that most of the accessory minerals crystallized in the microcline zone.

Some additional statements on the variation in the Stockholm pegmatites may now be made, but it must be pointed out at the beginning that these are an attempt to fix some rather diffuse trends, and that exceptions may be encountered.

There are pegmatites with grey microcline and others with red microcline. The former type is more often found near grey granite bodies, whereas the red type seems to be more independent or younger. Zoning is less marked in the

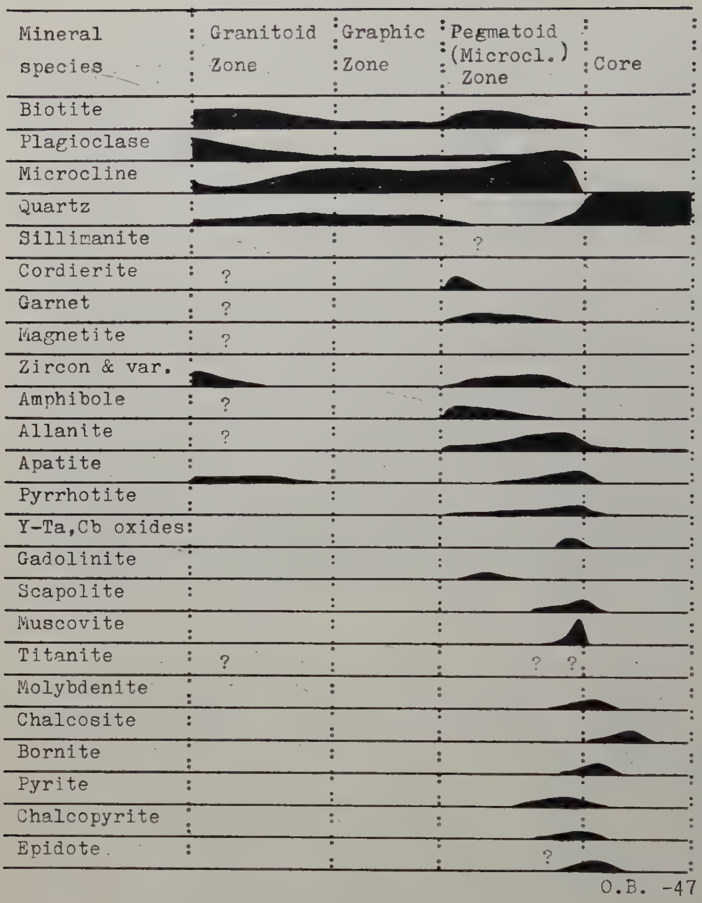

Fig. 3. Zonal distribution of minerals in the Stockholm pegmatites. »?» marks uncertain observation.

grey ones, but some of the red ones lack the earlier zones, i.e. the granitic border, and a few lack even the zone of graphic granite. Oligoclase, zircon, monazite, and pyrrhotite are more often found in the grey pegmatites, allanite is indifferent, and pyrite and molybdenite definitely are found more often in red pegmatites. There seems, also, to exist a tendency of displacement of minerals, such that those which may be found in the intermediate zone in the grey pegmatites, are sometimes found only in the border zone of the red ones. The distribution of zircon may be taken as an example of this.

The Stockholm pegmatites also furnish some observations of interest in connection with the problems of the origin of the internal zoning.

Regarding the zone of graphic granite one can often observe that the quartz individuals of the intergrowth are very small and even microscopic in the outer parts of the zone and that their size increases inwards. Further inwards the intergrowth ceases suddenly along a rather well defined boundary-surface. Inward from this zonal limit only microcline free of macroscopic quartz intergrowths is found. This microcline is crystallographically perfectly continuous

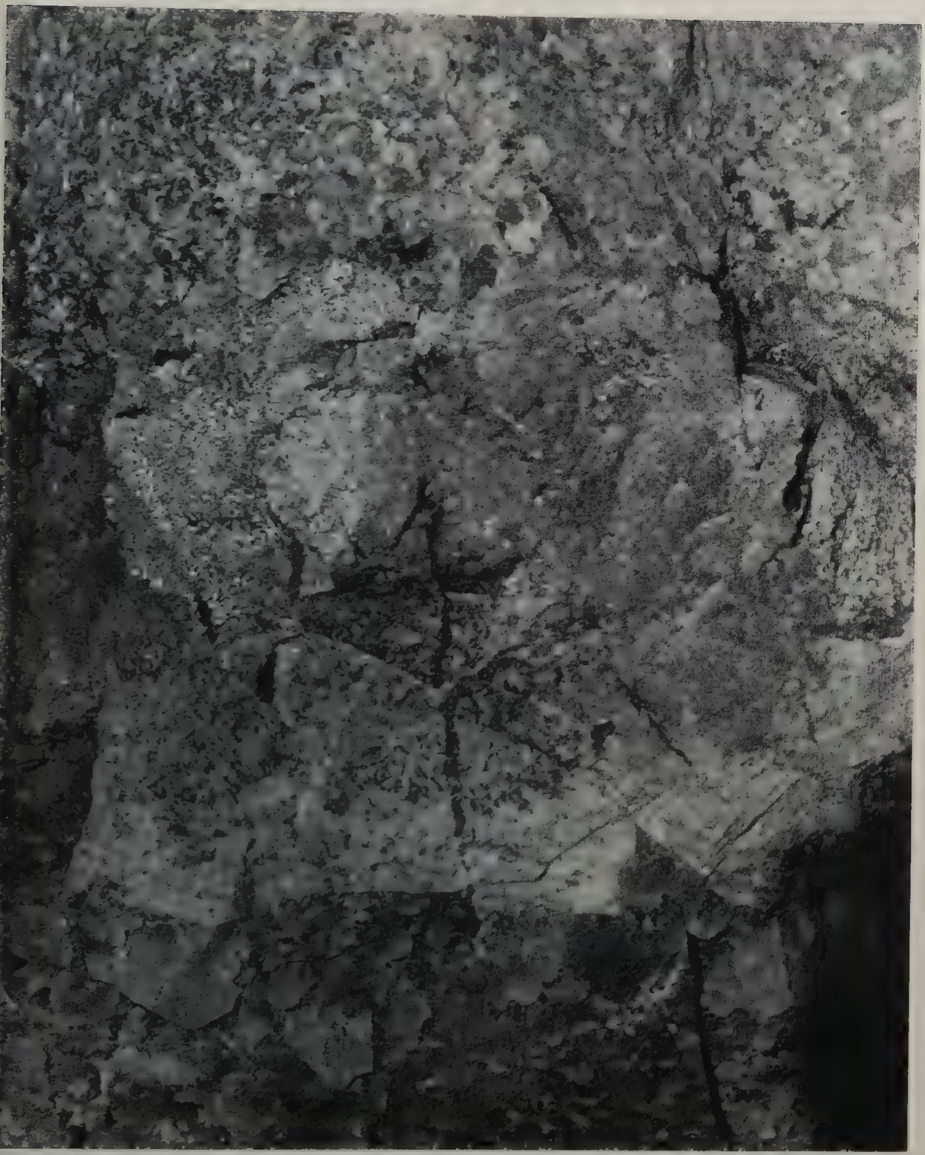

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Fig. 4. Section, from wall to center, of simple pegmatite, in outcrop. The granitoid zone (top) is followed inward (downward) by the zone of graphic granite. This is extremely finegrained, apparently homogeneous, in part (middle, right), and made up of »brush feldspar» (Bastin 1911), in part (middle, left). Size of quartz intergrowths increases inward. The pegmatoid zone, which follows next, is represented only by the quartz-free continuations of the microcline crystals of the graphic granite, which project into the quartz-core (dark-grey, bottom). The quartz ntergrowths of the graphic granite seem to be irregular in shape, but this is due to the nearly ongitudal sections and irregularities in the surface of exposure. 1.1:1. Kjellgrensgatan, Kungsholmen.

with that of the graphic granite, cf. Fig. 4. These relations have rarely been described, (cf., however, Bastin 1911, p. 23—25; Broch 1934, fig. 16 and p.

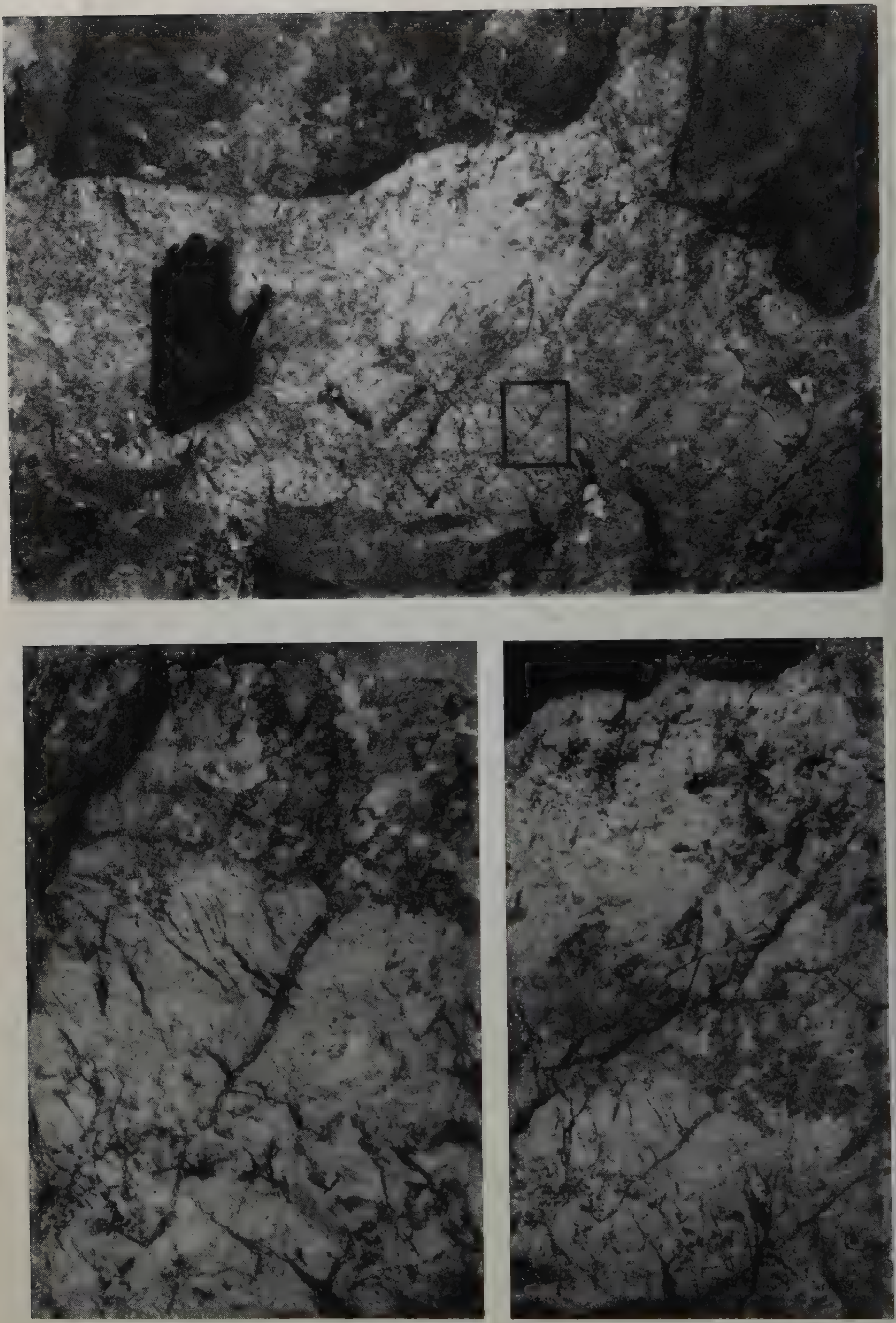

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Fig. 5. One and the same offshoot from the quartz-core filling a fracture in earlier zones. Dark grey is quartz, light grey is feldspar, black is biotite and white is snow. Norrtäljevägen, Stocksundstorp.

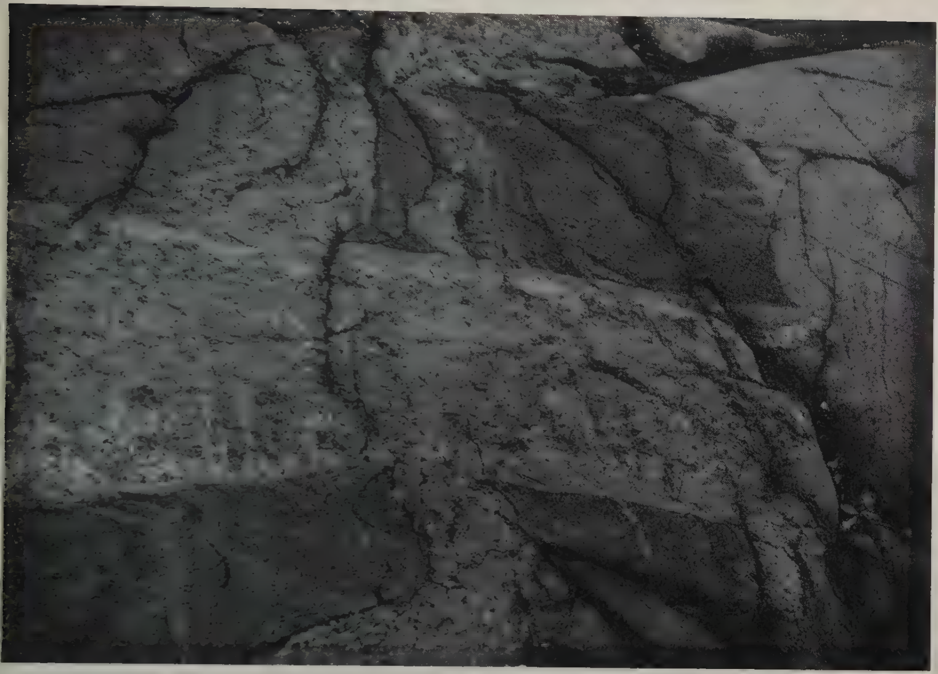

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Fig. 6. Early, bent and unzoned pegmatites (vertical), cut and displaced by straight and zoned pegmatite (horizontal), which in turn is cut by Stockholm granite, showing vertical »flow» lines. Note the continuity of the finegrained border zone of the horizontal dyke at its upper contact. 1:25. Stadshagen.

81; Shibata 1949, p. 23; Jahns 1955, p. 1098); but they may be quite common, for they easily escape observation in hand specimens or in large pegmatite bodies.

The sequence of zonal units is indicated by the fact that fractures in outer zones are sometimes filled by core quartz, cf. Fig. 5. The same feature has repeatedly been demonstrated by mapping of larger pegmatites, cf. Cameron *et. al.* (*loc. cit.,* p. 70—83). This certainly provides clear evidence of the fact that outer zones in pegmatite dykes solidified before the core.

Observations which seem to limit the time available for development of the internal zoning derive from relations with granitic and aplitic dykes. These, together with pegmatites, are intimately connected with the Stockholm granite. One can see zoned pegmatites which cut such dykes, and others which are cut by them, Fig. 6. A case of special significance is a pegmatite dyke in granite in which a small-grained dark granitic dyke takes the place of the core, Fig. 7; evidently it was injected after the microcline zone had formed, but before the quartz core was entirely solid. The dark dyke is probably not a normal unit in the zonal sequence of the pegmatite, for nearby it is found in independent dykes, one of which also cuts through a similar pegmatite, Fig. 8.

Herewith leave is taken of the simple and generally small granite pegmatites of Stockholm. There have been three reasons for starting the entire descriptive part with a perhaps lengthy account of the relations found here, namely

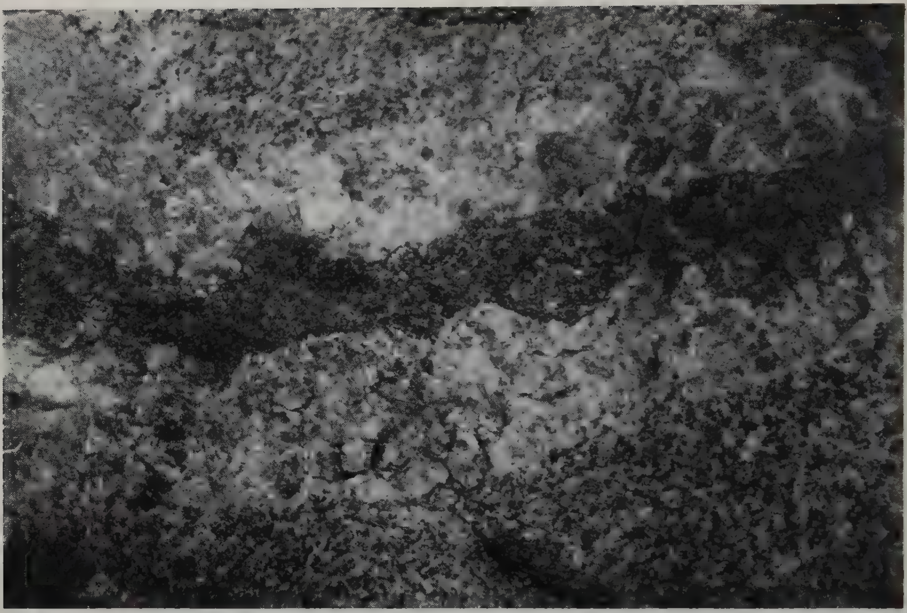

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Fig. 7. Dark, granitic rock taking the place of the regular quartz-core in a small pegmatite cutting Stockholm granite. 1:2. Mörbybacken, Norrtäljevägen.

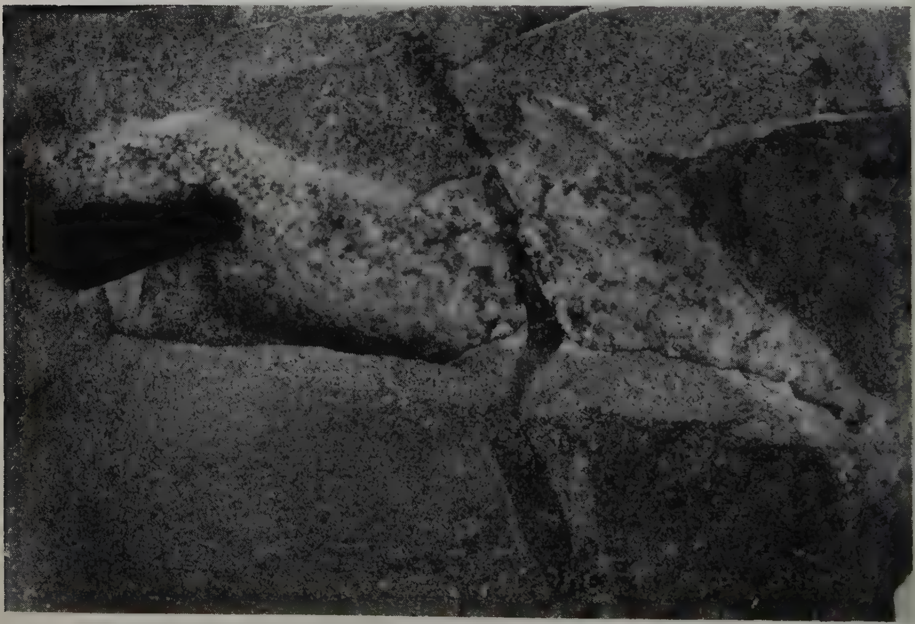

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Fig. 8. The same granitic rock cutting through a small pegmatite in Stockholm granite, thus proving that it is not a regular member of the zonal sequence in the pegmatite. Same locality.

1) the fact that in spite of their insignificant size and poor mineralization many of these pegmatites show very marked and complete internal zoning,

2) that features, which otherwise require detailed mapping in larger deposits, are easily observed,

3) that granite pegmatites of this relatively uninteresting type rarely have been studied in detail. Part of the material studied by RAMBERG (1956) may be of a similar nature, but evidently conditions regarding the field-relations to granite and crosscutting between pegmatites were less favourable in his field.

Other Similar Pegmatites

In order to show that the pattern described above is not confined to such unimportant pegmatites as those of the central Stockholm area, and also in order to indicate part of the variation possible within that zonal frame, we now proceed to other, more important, deposits of a similar zonal pattern.

Sweden

Ytterby. The Ytterby pegmatite, situated 18 km NE of Stockholm (40 km by road) is famous for being the source of minerals in which the elements tantalum, yttrium, ytterbium, terbium, and erbium were first discovered. It has been described by NORDENSKJÖLD (1908; mineralogy), FERSMAN (1931; paragenesis), and SUNDIUS (1948; geology and zoning). At Ytterby there is no nearby outcrop of Stockholm granite so that its relation to the pegmatite deposit remains a matter of opinion. Sundius is thus inclined to regard the pegmatite as an affiliation of nearby gneiss granite, whereas the present writer thinks that, in analogy with conditions of the central Stockholm area, the Ytterby pegmatite is genetically related to the Stockholm granite.

The part mined had a rather limited horizontal area, approximately 20 × 8 m at the surface. It has, however, been followed to a depth of about 170 m. It was made up of a series of quartz lenses, surrounded by coarse blocky microcline and oligoclase with plenty of biotite. The wall zone, in turn, is made up of graphic granite and the border zone, which is absent in places, is granitic with grain size increasing inward. This zonal sequence may still be observed at the surface. According to oral communication by the last mine captain (as quoted by Sundius), the quartz lenses with their feldspar shells pinched out completely in some places, and graphic granite then filled the entire space. The general zonal pattern of Ytterby corresponds very well with that of the pegmatites found in the central Stockholm area.

The accessory minerals are mainly confined to the microcline zone. This is at variance with the paragenetical analysis of the Ytterby pegmatite, which is given by Fersman. He places most of the dark accessories in his phase C, i.e. the zone of graphic granite, where they are, actually, not usually found, as evident from existing outcrops and numerous specimens. (Allanite, only, is also found in the zone of graphic granite.) On the other hand the sequential order of minerals as given by Fersman seems to be quite correct.

The outermost part of the intermediate zone is rather rich in oligoclase and biotite, allanite (orthite) is quite common and may still be seen in the walls of the mine opening. Slightly later in the order of crystallization are gadolinite, fergusonite, yttrotantalite, xenotime, and anderbergite which minerals are characteristically found attached to large flakes or books of biotite. Garnet is quite common, sometimes it is found in greater concentrations near quartz with pyrrhotite, or replacing microcline along indistinct veins. Muscovite is far less common than biotite, it seems to be formed distinctly later and is usually found together with microcline and quartz, thus presumably originating from the inner intermediate zone. Apatite, magnetite, pyrite, native bismuth, and molybdenite are found occasionally. Beryl, chrysoberyl, cordierite, and tourmaline have also been reported from Ytterby. They are very rare.

Derome. At Derome, Halland, in the south-western part of Sweden, there are a number of pegmatite quarries, most of which are of minor importance. The biggest ones may be mentioned here. They display the general zonal sequence but are not noteworthy because of accessory minerals, only magnetite, pyrite, allanite, and molybdenite (NW quarries) have been found so far. They seem, however, to be rather exceptional in their high content of "basic" constituents, plagioclase and biotite being very important. In the westernmost quarry also large individual crystals of hornblende, 0.9 m long and 0.25 m in diam., have been found. Likewise in the southern quarry, biotite, in the form of giant flakes some square meters in size, was found to reach deep into the quartz core.

Quite a number of the other Swedish pegmatites show a similar zonal pattern, but there seems to be little justification for describing, or even mentioning, them all here. It will suffice to note that in the same region as Derome are found *Gräne,* Holsljunga, where euxenite has been found (Hedström 1923), *Skillnabo* with allanite, rutile, alvite, and uraninite, the two latter minerals sometimes characteristically grown on big platy crystals of ilmenite, together with other minerals not yet identified, but definitely deserving a special study; *Ingelsbo* with euxenite and fergusonite (?), and *Nohl,* with euxenite and samarskite (blomstrandite and nohlite) (Nordenskiöld 1872; Lindström 1874). A very complete compilation of Swedish pegmatite quarries, with details of geology and mineralogy and references to pertinent literature, has been published by Sundius (1952). Two figures are finally reproduced from this paper, as very good illustrations of the zonal pattern here discussed, and, at the same time, two unusually early examples of careful mapping of the internal structure of granite pegmatites, Figs. 9, 10.

Southern Norway

The pegmatites of Southern Norway have been quarried for about 165 years, and have been studied in detail by generations of scientists from mineralogical,

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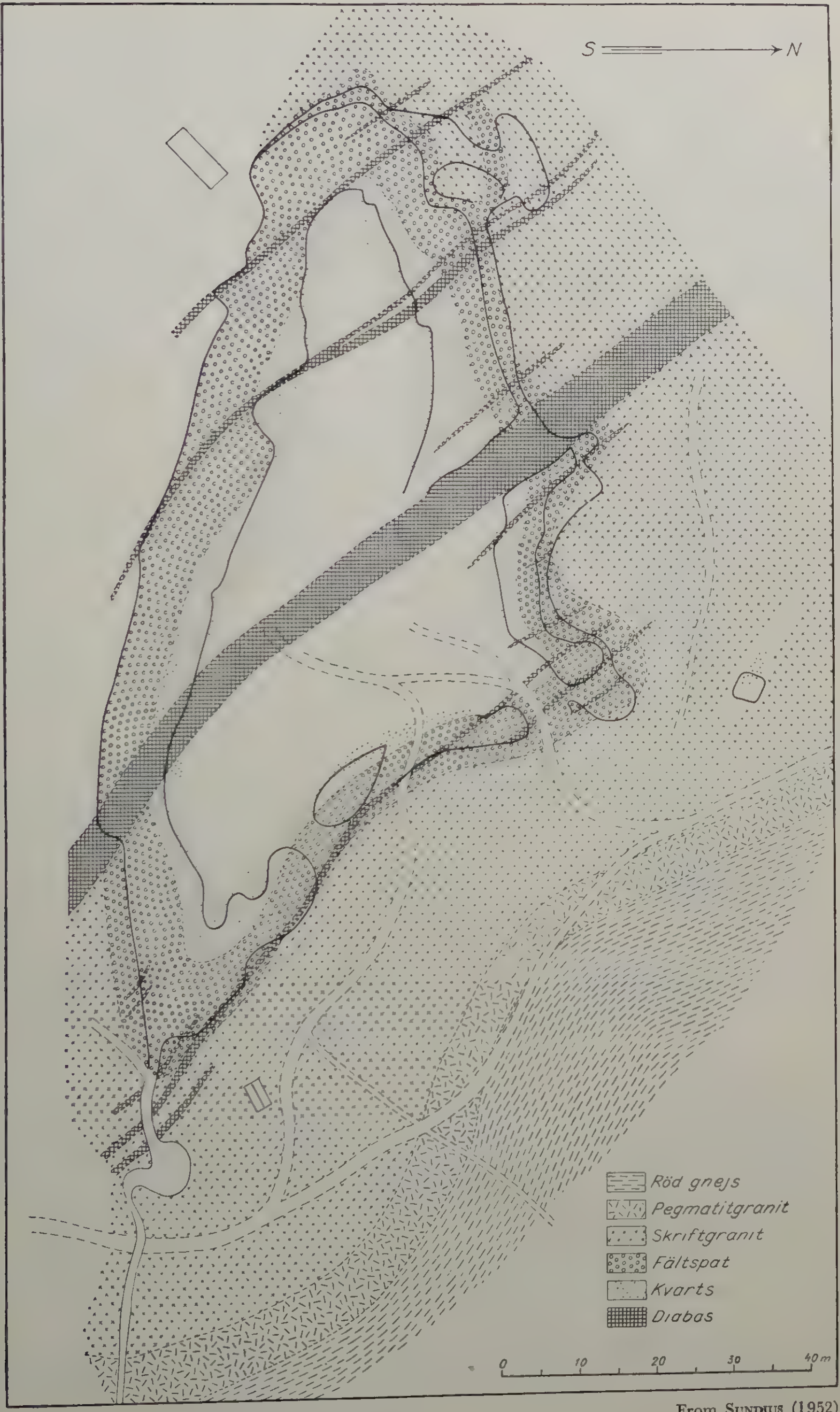
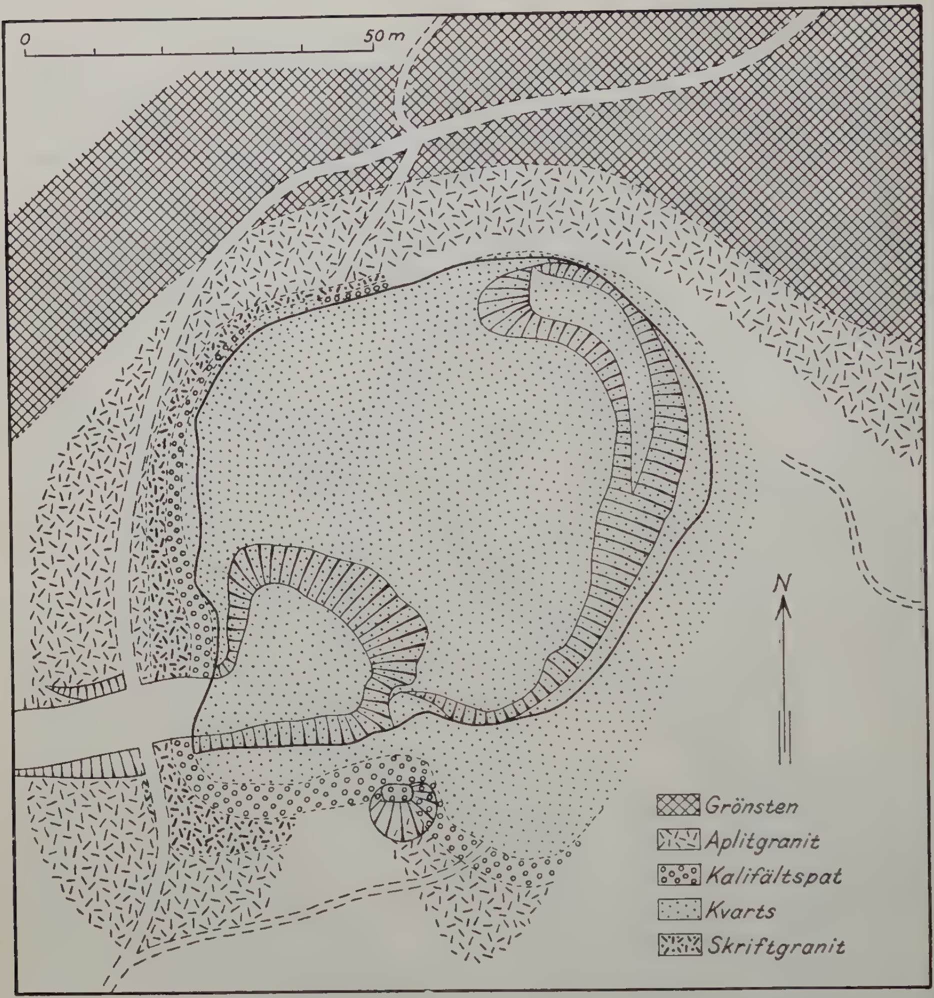
Fig. 9. Drömgruvan, as mapped by H. E. Johansson around 1912.
Röd gnejs = red gneiss; pegmatitgranit = pegmatitic granite; skriftgranit = graphic granite; fältspat = feldspar; kvarts = quartz; diabas = diabase.



From Sundius (1952).



From Sundius (1952).

Fig. 10. Mejdåsens quartz-quarry, as mapped by H. E. Johansson around 1915. Grönsten = diorite; aplitgranit = aplitic granite; kalifältspat = potassium feldspar; kvarts = quartz; skriftgranit = graphic granite.

paragenetical, geological, petrogenetical, and geochemical points of view. Here it is necessary to concentrate on a few results of this study, which are of special importance in the present connection. Brögger (1906, p. 24, 25) has shown that the various pegmatite deposits of the region may be divided into a number of types, namely:

1) Ordinary granite pegmatites, with microcline-perthite, quartz, and biotite. These may, on account of accessory minerals, be further divided into subtypes with

a) Columbite, samarskite, and monazite;

b) Euxenite, allanite, yttrotitanite, thorite, xenotime etc.

2) Tourmaline-bearing granite pegmatites.
3) Muscovite-rich pegmatites.

The pegmatite deposits of Tangen and Karlstadsgangen eventually constitute a separate group, differing in certain respects from the others.

Otherwise this grouping has stood up rather well, thus Barth (1928 a, p. 414) confirms it, and the single major addition of more recent times is a local occurrence with amazonite, cleavelandite, lepidolite, cassiterite etc. as typical minerals (Oftedal 1942).

No. 1 b of Brögger's groups displays a zonal sequence in close conformity with the basic pattern. It has been analyzed by Fersman (1931, p. 162). He gives the following zonal sequence:

Enclosing formation Amphibolite	Colour dark green	Thickness —
I Border (salband) rich in biotite (or hornblende)	black	up to 20 cm
II Plagioclase + quartz with biotite and magnetite, irregular graphic structure	white	» » 300 cm
III Reddish graphic granite (microcline and quartz)	reddish	» » 1 000 cm
IV Red microcline in big crystals + quartz	»	» » 300 cm
V Quartz with rare microcline	grey	» » 1 000 cm
VI Miarolitic cavities (very rare)		

The original publications should be consulted for details (Brögger 1881, 1906, 1922; Andersen 1926; Barth 1928, 1931; Fersman 1931; Broch 1934; Björlykke 1937; Adamson 1942).

Northern Italy

At *Baveno,* in Northern Italy, near the western shore of Lago Maggiore, a body of grey, massive, granite of small and even grain intrudes a series of sedimentary rocks, which show clear evidence of contact metamorphism. Within the granite (which strongly resembles the Stockholm granite) are found numerous pegmatite lenses, often reaching some meters in length and about 0.5 m in thickness. Their zonal sequence conforms exactly with the basic pattern of the Stockholm pegmatites. In the intermediate zone magnetite, allanite (?), and gadolinite (?) have been noted. In places the quartz core is partially absent, the corresponding space being empty. On the walls of these cavities are found crystals of numerous minerals, among others the famous Baveno feldspar twins. Most of these minerals, many of which are great rarities, fall outside the framework of the simple basic pattern, and are not considered here.

Japan and Korea

Shibata (1949, p. 20) gives the following notes on the most common type of pegmatite from his working region.

"The outermost zone consists of fine grained granitic part, sometimes containing fine crystals of garnet.

The next zone consists of graphic granite with long platy crystals of biotite, sometimes dendritic.

The next zone consists of large crystals of microcline, oligoclase, quartz and biotite or muscovite.

The central zone consists of quartz.

The structure in generally symmetrical, especially in a vertical vein. While in the vein having a low angle of inclination, asymmetrical structure is evident. Commonly the coarse part is found in the upper part of the vein."

Summary on Simple Granitic Pegmatites

Simple granitic pegmatites, as exemplified above, may now be characterized in the following way. They are generally of simple structure and mineralogy. The zoning usually conforms with the contacts and, when complete, is made up of the four major units given. Mineralogically these pegmatites consist of microcline, plagioclase (oligoclase as a rule), biotite, and quartz; hornblende, muscovite, and tourmaline are accidental and subordinate. Accessory minerals are the same as those often found in granites i.e. magnetite, apatite, zircon, allanite, titanite, xenotime, and monazite. Garnet is quite common. Sometimes one or more of the following minerals, or related species, are found, ilmenite, gadolinite, fergusonite, yttrotantalite, euxenite, uraninite, and molybdenite, pyrite, pyrrhotite, and chalcopyrite. The accessory minerals are most plentiful in the intermediate zone of coarse microcline. The earlier rare-earth minerals are often best developed in the outer part of that zone, sometimes characteristically attached to biotite. The sulphides are late and usually found near the core margin. (Massive pyrite has been noted as an apophysis from the quartz core, Stackebo, Västergötland.)

COMPLICATING FEATURES

The complicating features necessary to describe many complex granite pegmatites on the basis of the pattern found in simple pegmatites, comprise the appearance of muscovite, late albite, lithium minerals, and phosphate minerals, etc. Each of these steps may be accompanied by a characteristic suite of associated minerals. However, a tendency seems to exist, in more complex granite pegmatites, towards degeneration and partial reversion of the basic zonal pattern. From personal experience the writer knows of only a few cases where a pegmatite deposit with a well developed phase of late albite exhibits the complete basic zonal pattern, and just one, not very clear, case (Suoravaara, Norrbotten) of complete simple zoning in combination with a weak lithia phase. It therefore seems appropiate to begin with an account of pegmatite deposits with muscovite and late albite, to follow it up with an account of changes in zoning, in which muscovite and albite play a prominent rôle, and finally end up with lithium, and other, late, mineralizations.

Muscovite-bearing Pegmatites

The apperance of muscovite is here chosen as the first complicating feature, because it is the most common one, and the one implying least change in the simple basic pattern. It is furthermore very often found independent of later mineralizations, whereas these are always accompanied by, and often preceded by, muscovite.

Muscovite may appear in any stage of the development of the zonal pattern, evidently without causing great changes in it. This is illustrated by the following examples.

Brattås, Orust. At Brattås, on the island of Orust, Southwest Sweden, there are two large pegmatite quarries, abandoned long ago, and one small one, which was mined for mica during the Second World War. Here we are concerned with the biggest one. The internal zoning is clearly revealed by a sort of bridge of pegmatite left standing over the eastern part of the large pit. The following features can here be observed. The small grain of the border zone rapidly becomes coarse. Microcline, plagioclase, biotite, and a little quartz are the main constituents. The amount of plagioclase decreases inward. A zone of scattered "graphic granite" crystals is found next, microcline as well as plagioclase exhibit this typical development. At the inner border of this zone appear plates of mica, composed of biotite and muscovite more or less regularly intergrown. From here, inward, muscovite is the only mica found. Likewise plagioclase disappears and microcline strongly dominates, i.e. this zone constitutes a typical microcline unit. It is followed by the ordinary quartz core, and near its margin a few small crystals of beryl may be found. These are grown on the microcline and project into the quartz. Besides these minerals, garnet is abundant, and on the dump a few pieces of amazonite were found.

That muscovite appeared right at the inner border of the graphic granite zone is merely accidental. Other relationships are often found, for instance on the island of *Utö,* in the archipelago of Stockholm. Here, on its western shore, many straight parallel-walled pegmatite dykes are to be seen. Their zoning is simple, the quartz core, the microcline zone, and the zone of graphic granite are easily distinguished. Mineralogically they consist of microcline and quartz. The muscovite is found in varying amounts right from the margins to the core. Biotite is absent. Black tourmaline and, sometimes, also garnet are present in places. Blue-green apatite in small grains is occasionally found.

A special, but quite common, mode of occurrence of muscovite in the zonal framework may be exemplified by mica-bearing pegmatites N of Luanda, Angola. Here muscovite is concentrated at the inner margin of the microcline zone, near the border of the quartz core. Barrel-shaped muscovite crystals may reach 200 kgs in weight.

Granite pegmatites of similar simple zoning and carrying muscovite, and in places varying amounts of black tourmaline, garnet, beryl, apatite, sometimes also triplite and columbite, are so widespread that no further examples are needed in this connection. It may be concluded that muscovite in granite pegmatites can start to form at any stage of zonal development, and that the appearance of this, petrogenetically, very important mineral by itself does not imply any great changes in the zonal or mineralogical pattern. Typical accompanying minerals have been listed above. These minerals tend to be more frequent near the core quartz.

Pegmatites with Late Albite

Albite, often sugar-grained or in the form of cleavelandite, characterizes stages of intensive mineralization in granite pegmatites. It may be found as a normal constituent of the inner intermediate zone but more frequently it appears as fracture fillings or replacement units, which traverse, soak, or obliterate the normal zonal arrangement of the pegmatite body. The Högsbo pegmatite may be taken as an example which clearly illustrates these relations.

At *Högsbo,* near Gothenburg, in southwestern Sweden, two large pegmatite dykes cross a slightly metamorphic hyperite.[1] The smaller pegmatite body shows no very marked zoning. The quartz core is marked by a series of small quartz pods, and at their margin a tendency towards development of a microcline zone may be noted. Here a little muscovite and traces of fluorite are to be seen, otherwise this dyke is made up of a bulky mass of microcline, plagioclase, some quartz, and large, distorted, flakes of biotite.

The larger pegmatite body, which lies only 15 m to the north of the preceding one, in contrast displays beautiful internal zoning. It has been extensively mined. The following description refers to the conditions as found in 1951—52.

Nearest the wallrock (abundant biotite has formed in the hyperite), comes a narrow, biotite-bearing, border zone of finer grain, followed by an equally narrow zone of graphic granite. This is characterized by very coarse quartz hieroglypts, in this respect reminiscent of the graphic granite of Eräjärvi, cf. von Volborth (1954, Fig. 6). Then begins the microcline zone, the outer parts of which are still rich in plagioclase and great oblong and distorted flakes of biotite. The inner parts are made up of very large microcline crystals, some of which reach a maximum length of four meters. They are often broken and the wedge-shaped fissures are filled by quartz, which constitutes apophysae from the quartz core. The microcline crystals show a preferred orientation with the a-axis more or less perpendicular to the walls. Near the core margin great prisms of greenish-yellow, non-translucent, beryl are to be found, cf. Fig. 24.

The inner part of the microcline zone is transected by a great number of albite veins of slightly varying types, which evidently were emplaced at slightly different times. Directions parallel to the walls or the core margin prevail to some extent. Along these veins considerable replacement of the microcline by large books of muscovite has taken place, Fig. 11. Likewise a great deal of the particular mineralization of this pegmatite deposit is confined to these albite veins. Here are found among others, garnet, columbite, monazite, beryl, yttrotantalite, bismuth minerals, and colourless, or dark purple, fluorite, Fig. 12, 13, 14, cf. Sundius (1950). To a lesser extent these veins also brecciate the quartz

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[1] noritic amphibolite.

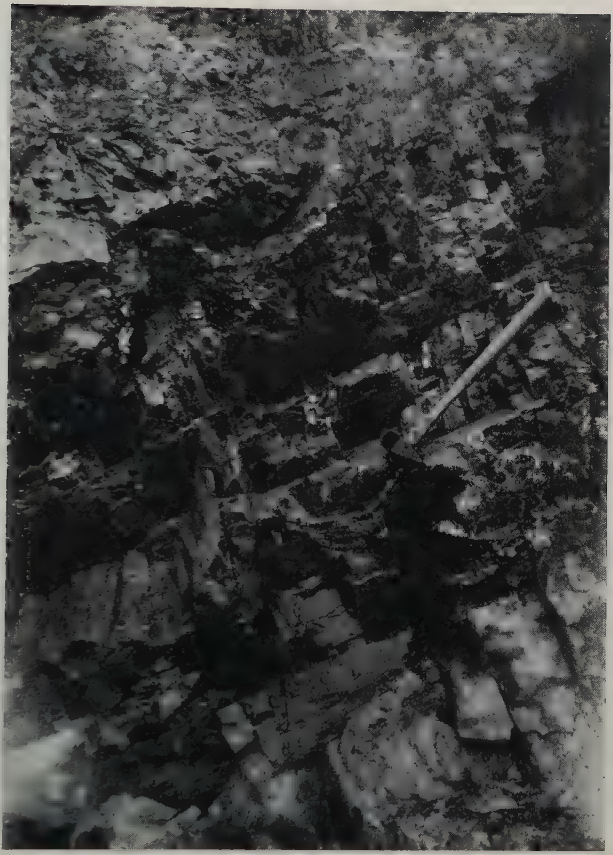


Fig. 11. Giant microcline crystal at the margin of the quartz core (bottom). The feldspar is slightly brecciated by the quartz. It is also replaced by muscovite in large, irregular books and by late albite in narrow veins. Microcline is grey, albite white, muscovite dark and quartz cloudy white. Högsbo, 1950.

O. B. phot.

core, sometimes giving rise to a coarse, pseudo-graphic, intergrowth of quartz and albite, Fig. 15. Many of the cleavelandite veins, also some of those which transsect part of the central quartz core, are found to have quartz cores of their own.

A special variety of late albite is represented by aplitic veins, which constitute typical fracture fillings of sugary albite with numerous red-brown garnets of a pinheads size, and occasional small blue specks of apatite.

The core of the Högsbo pegmatite is made up of white massive quartz, which may occupy three quarters of the width of the dyke, when it reaches approximately ten meters in thickness (1951). In addition to quartz there is found green, sometimes rather clear, fluorite, which actually forms peripheral parts of the core, in pods of several hundred kilograms. As a rarity blue-green, rather translucent, beryl may be found within the quartz. The beryl crystals are beautifully zoned, with the translucent material enclosing an ordinary dull yellowish core. Late albite mineralization has befallen the quartz core only near the margins, the interior, larger, part of the core is left perfectly intact and consists exclusively of quartz, cf. Fig. 17.

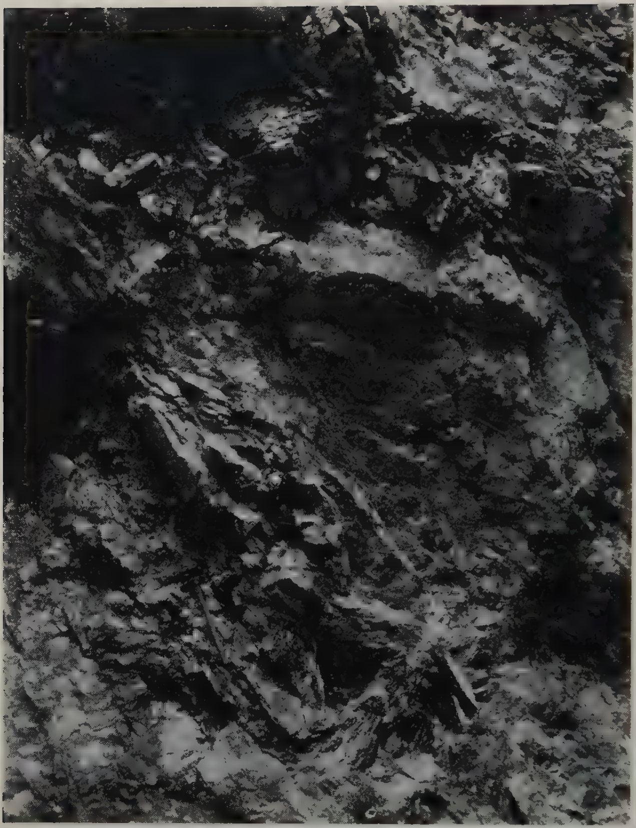


Fig. 12. Large microcline crystals veined by albite with much muscovite. The albite mineralization follows the diagonal line from the upper left to the lower right corner, and lies horizontally in the upper part of the photograph. Microcline is grey, albite light and muscovite dark and bladed. The dark lump in the upper left margin, which is surrounded by radial cracks, is monazite. Columbite was also found in this spot. 1:40. Högsbo 1951.

O. B. phot.

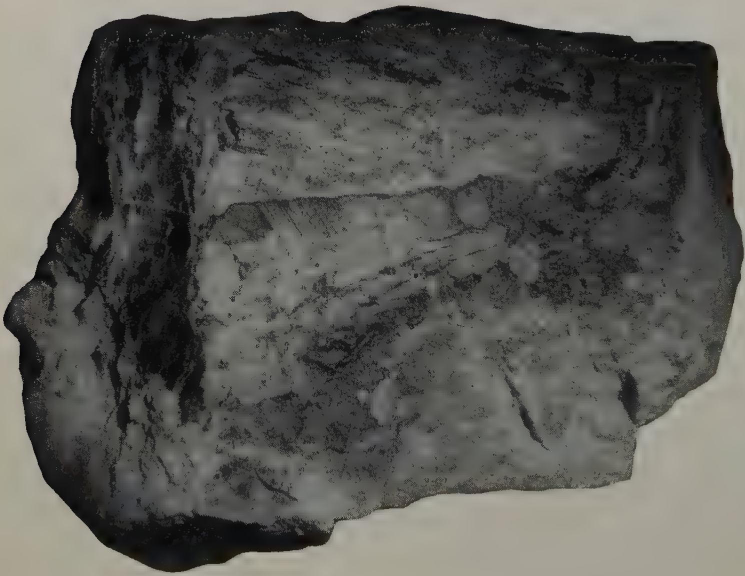
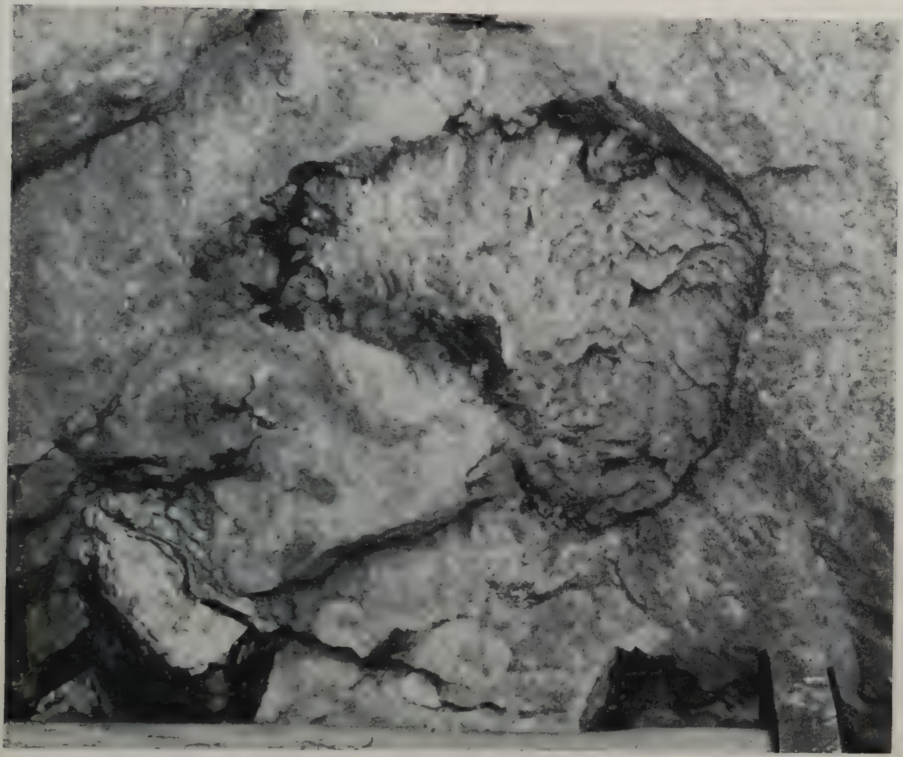


Fig. 13. Columbite, grey, striated, in sugar-grained albite, light, 1:2. Högsbo.

O. B. coll. & phot.

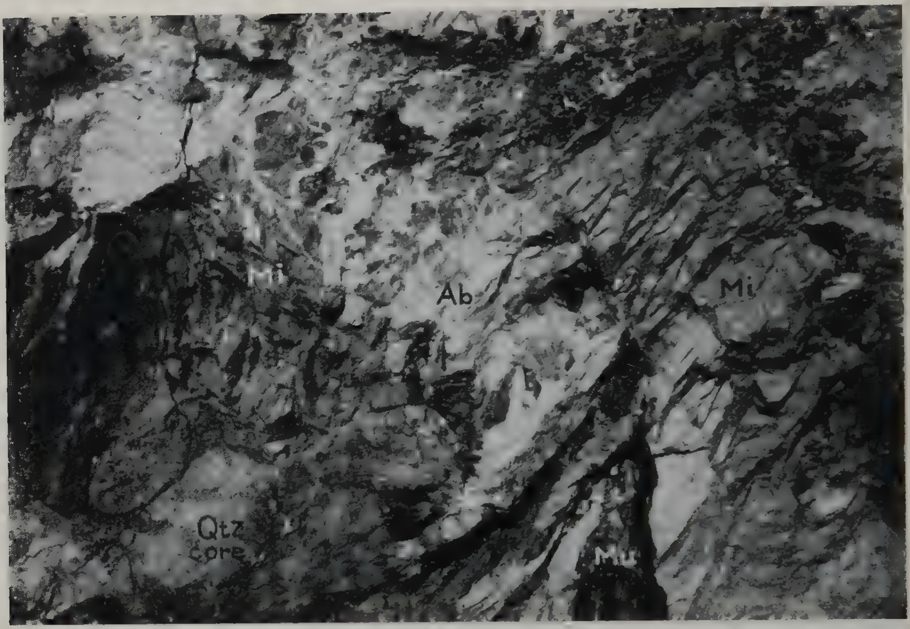


O. B. phot.

Fig. 14. Rounded lump of fluorite between albite-rock with muscovite (in the lower left corner) and core-quartz (bottom, middle). 1:5. Högsbo, 1958.

Before ending the description of the Högsbo deposit a special feature, believed to be of some importance, must be mentioned. It is connected with the occurrence of a large xenolith of hyperite near the middle of the deposit. Its maximum dimensions, about perpendicular to the strike of the pegmatite dyke, (E—W) were 2 × 3 meters as exposed in 1951. Probably this xenolith is due to the fact that the pegmatite body occupies the space of a complex, branching, fracture, and originally the xenolith must have been part of the wall between two eastern branches. This xenolith was surrounded by a shell of typical microcline zone, having a thickness of 0.5 to 1.5 meters, and comprising all minerals typical of this zonal unit, including some very large crystals of beryl. The mass of this mineral found around the xenolith could be estimated as being about 300 kilograms. It was located near the core margin, and the xenolith with its mantle of microcline zone was surrounded by the branching quartz core on all exposed faces, that is in all directions except in the rear.

Late albite and associated mineralization is a wide-spread phenomenon of granite pegmatites, numerous examples are given by Cameron *et al.* (1949). Other Swedish occurrences are *Skuleboda* with yttrotantalite, muromontite (Be-allanite), and *Gundlebo,* topaz, amazonite, lepidolite, and fluorite, Alm-



O. B. phot.

Fig. 15. Large microcline crystals (grey, with regular cleavage) embedded in and partly replaced by albite (white), muscovite (dark and bladed), and quartz (dark grey). Albite and quartz form a coarse, pseudographic intergrowth. Lighter grey core-quartz in the low left. 1:25 Högsbo 1958.

STRÖM (1931), SANDEGREN (1931), QUENSEL (1944), SUNDIUS (1942, 1952); *Getlycke:* — calcite, LOOSTRÖM (1930), SUNDIUS (1937, 52); *Timmerhult:* — beryl, columbite, monazite, microlite, fluorite, A. E. NORDENSKIÖLD (1899), A. LINDSTRÖM (1902), ALMSTRÖM (1922), SUNDIUS (1952); other pegmatite deposits on the island of Orust, SUNDIUS (1952); *Stripåsen:* — topaz, TENOW (1900); *Norrö:* — garnet, beryl, tourmaline, triphyline, arrojadite, cassiterie (Ramdohr), and sulphides, ERIKSSON (1946), LINDBERG (1950); *Riddarho:* — amazonite, lepidolite, and fluorite, W. LARSSON in SUNDIUS (1952); and in addition to these the pegmatite deposits of Utö and Varuträsk, where lithium mineralization is a dominating factor.

From descriptions in literature, however, it seems that zoning, in the majority of occurrences with late albite mineralization, shows less similarity with the zoning of simple granite pegmatites than is the case at Högsbo. Nevertheless mineralization, paragenesis, and textural relations are often remarkably alike. Thus, in spite of differences in zoning and size, both mineral paragenesis and textures at Högsbo are very similar to those of the Globe pegmatite as described by WRIGHT (1948), and, in fact, most of the illustrations of textures in that paper could equally well refer to Högsbo. One difference is that at Högsbo the monazite is found in fairly large lumps (40 kg) and not as feathery aggregates, but columbite often shows that peculiar structure.

Other examples of pegmatites with similar paragenesis are given by HEINRICH

(1948), Staatz and Trites (1955), Gevers (1937) and many others. The mineral associations listed above seem to be fairly representative, but naturally not at all exhaustive. Thus uraninite, gadolinite, and many other minerals could be added.

Deviations in Zoning

Deviations from the basic zonal pattern of simple granite pegmatites are essentially of two types. One type implies a reduction in the number of zones, whereas the sequence of the zones which are still represented is kept in accord with that of the basic pattern. The second type will here be regarded as implying reversions in the zonal sequence.

Reduction in the Number of Zones

The first type of deviation is trivial, and found in all types of granite pegmatites, even the simple ones. It may arise either from poor zoning or from reduction, leading ultimately to complete absence of certain zonal units. Thus poor zoning is shown by undifferentiated granite pegmatites, whereas others show tendencies to develop small scattered quartz cores and surrounding microcline zones. The minor pegmatite body at Högsbo may be named as an example. In other pegmatite dykes the outer zones may be well developed but segregation of microcline from core quartz is incomplete. This is often found in the Stockholm pegmatites as mentioned in the section dealing with them. Other simple granite pegmatites are exclusively or dominantly of graphic granite, examples are found at Härlanda, Gothenburg, and S. of Lansjärv, Norrbotten, Sweden. Forshammar, Västmanland, one of the largest pegmatite quarries in Sweden, likewise seems to belong to this type, eventual equivalents to the microcline zone and quartz core, late albite and muscovite do occur but are very subordinate, Sundius (1952).

In other pegmatites the reverse is true, so that the zone of graphic granite is greatly reduced or entirely absent. Brattås, as mentioned above, is an example of the former case, and many zoned Stockholm pegmatites lack graphic granite. Also the border zone of granitic or aplitic nature may similarly be absent. This seems to be the case in many muscovite-bearing pegmatites, which start off with graphic granite right from the wall. An example of this with an unusually complete array of later mineralizations is given by I. A. Smirnov in Vlasov (1955).

Reversions in the Zonal Sequence

The second type of deviations from the basic zonal pattern of simple granite pegmatites, namely what is here looked upon as reversions in the zonal sequence, cannot be considered in the same simple way as the first one. It evidently marks some more fundamental change in conditions during crystallization. It is, as a rule, not found in simple pegmatites, but in complex ones, and clearly it is most frequent in pegmatites showing complex and multistage mineralization. However, the most radical and evident deviation of this type is illustrated by a type of quartz dyke with core-like lenticular stringers or isolated crystals of microcline near its median plane. Examples of this are quite common and have been discussed repeatedly, cf. JAHNS (1955, p. 1103—1106). Quite a number of such dykes occur in the Gothenburg region of Sweden, for instance along the shore from Ganle to Fiskebäck and at Hinsholmen. Together with the microcline, muscovite, platy crystals of albite, a little apatite, and magnetite were noted, these minerals sometimes being found on the walls of small cavities in the central parts of the dykes. In accordance with the view taken here these central feldspathic parts correspond to the microcline zone and core margin of ordinary pegmatites, whereas the surrounding quartz is equivalent to the usual quartz core.

Far more common, and often very important as deposits of commercial mica, are those granite pegmatites which show concentrations of muscovite along their margins.

An example of this, which otherwise is of quite simple zoning and mineralogy, is a small pegmatite deposit on the island of *Donsö* in the archipelago of Gothenburg. Here the bedrock is made up of strongly pegmatite-veined, more or less stratified, gneiss, rich in biotite and muscovite. Sometimes the pegmatite veins swell to irregular lenticular bodies some meters wide. A big lens of this kind has been temporarily quarried for feldspar. As a result of its irregular shape the internal zoning is not as clear as that of the Brattås deposit, with which it is geologically related. The zone of graphic granite thus is entirely absent, likewise early plagioclase seems to be altogether lacking. Zoning is instead marked by the well-developed quartz core and by the distribution of muscovite. This mineral, of very poor quality and specked with garnets, occurs as big books in pods along the outer margins of the pegmatite and along the core margin. Within these muscovite books, and also growing from microcline at the core margin, and projecting into the quartz, crystals of beryl are quite common. The prismatic crystals of beryl are long and slender within the muscovite, whereas when growing free into the quartz core they are stout. A small amount of beautifully blue apatite was found in this pegmatite, as also were small vugs lined with crystals of quartz, feldspar, and apatite. These features, however, are rather insignificant, the interesting feature of this pegmatite deposit being the deviation in zoning from the basic pattern of simple pegmatites. This departure is characterized by the notable similarity between the outer margins of the pegmatite lens and the margins against the quartz core. It is marked mineralogically mainly by the concentration of muscovite and quartz and the suppression of microcline. From the outer margins, and inward, there is a gradual transition to normal zoning through the decrease of muscovite and increase of microcline.

Pegmatites with similar muscovite-rich outer margins are not very common in Sweden. Some pegmatite deposits on the island of Orust show the same feature, other occurrences are Berghem (Västerlanda) in Bohuslän, Skuleboda, Väne Ryr; and Norrö, in the archipelago of Stockholm, cf. SUNDIUS (1952). The remarkable Varuträsk deposit, well known through the exhaustive investigations by Quensel also exhibits this type of zoning in great clarity. Here the outer margins to considerable width are almost exclusively made up of muscovite and quartz, with small amounts of black tourmaline, a little garnet, and eventually also traces of apatite and columbite. As a complication, a great deal of later cleavelandite mineralization invades also these outer parts of the pegmatite body.

One more variant of this type of zoning must be mentioned. It is less conspicuous and represented by pegmatites where the outermost zone is composed of plagioclase, muscovite, microcline, and quartz. Evidently it is very close to the former type of zoning. Perstorp, Östergötland, Sweden, is an example of this. It is otherwise a normal granite pegmatite, where the quartz core and surrounding microcline zone formed a series of lenses. Muscovite, beryl, and black tourmaline are characteristic constituents. Late albite is found. Sulphides and a thucholite-like carbon compound are found in places only, and once triplite in very big lumps (1 m diam.) was observed by E. W. Heinrich and the writer, cf. also SUNDIUS (1952).

Finland

In the parish of Eräjärvi, Finland, pegmatite bodies often show similar outer margins, VON VOLBORTH (1954, p. 16). In the special case of the deposit of Viitaniemi, which has been described in greater detail because of its remarkable Li- and phosphate mineralization, these outer zones of the pegmatite carry quartz, muscovite, albite, microcline, tourmaline, and tapering beryl crystals of slender shape. Again this mineral asemblage is reminiscent of the minerals found near the core margin in mineralogically, much simpler pegmatite deposits. The Viitaniemi pegmatite is also of great interest because VON VOLBORTH (loc. cit., p. 19) has been able to trace the original zoning in spite of the later replacements and fracture fillings. Thus gigantic microcline crystals in milky and smoky quartz are found to characterize the intermediate zone of the deposit, and its boundary towards the wall zone is marked by a scattered occurrence of graphic granite.

The United States

From the U. S. A. the sequence of mineral assemblages of major pegmatite districts has been tabulated by CAMERON et al. (1949, table 1, p. 61). From this table it is evident that in three out of four major pegmatite districts the special type of zoning discussed in this section seems to be the rule, and only the pegmatites of the Petaca district, New Mexico, seem to be closer to what is taken as the basic zonal pattern in the present paper.

Again the first four mineral assemblages listed in that tabulation, namely 1) Plagioclase—quartz—muscovite; 2) Plagioclase—quartz; 3) Quartz—perthite—plagioclase, with or without muscovite, with or without biotite; and 4) Perthite—quartz show the same tendency towards development of "normal" zoning by decrease of muscovite and increase of microcline. Plagioclase apparently is quite stable, but note the assemblage 1. a) Quartz—muscovite; of the same presentation. Cf also Varuträsk. Furthermore in two of the pegmatite districts, namely "Southeastern States" and Petaca, the assemblage no. 4 is directly followed by the quartz core, whereas in the two remaining districts a number of other mineral assemblages intervene.

Additional Deviations

Two rather special types of zoning may also be mentioned here, namely 1) the case when the pegmatite occupies a composite fracture and thus shows a rather complex arrangement of otherwise normal zonal units; and 2) the case when a number of zonal units are missing because of tectonic interferences. (Telescoping of individual zones is not considered here.) The first case is possibly illustrated by the zoning of the Kolsva deposit, Västmanland, Sweden, as described by HJELMQVIST (1944). The other case may apply to the pegmatite deposits of the Spruce Pine district, North Carolina, MAURICE (1940). These are characterized by the combination of muscovite and calcic oligoclase, and show signs of strong, pre-muscovite (?) shearing.

Summary on Deviations in Zoning

These two latter types of deviation from the basic zonal pattern of simple granite pegmatites may be regarded as more or less accidental in nature, and this also to some extent applies to the first type. The main purpose of this entire section has been to indicate some, more regular, features of the zonal pattern of granite pegmatites as illustrated by the second type of deviations. These offer the following aspects:

1) Some frequently observed and described types of zoning in granitic pegmatites mark systematic deviations from the basic zonal pattern of simple granite pegmatites;

2) These systematic deviations are found in a number of variants; for instance the extreme case where the outer parts of the body are made up exclusively of quartz and the interior of the body consists of feldspar with some muscovite, or others where the outer parts are made up of mineral assemblages like quartz—muscovite, plagioclase—quartz—muscovite, plagioclase—quartz—muscovite—microcline respectively; with tourmaline, beryl, columbite, apatite, and sulphides as typical accessories;

3) The mineralogic composition of these outer zones resembles, both in major components and accessories (with the exception of the An-component), inner parts of other pegmatites of normal zoning of comparable mineralogy, and especially the core and core margins;

4) These systematic deviations in zoning are often combined with a tendency towards normal zoning in the interior of the same pegmatite body. Thus the normal microcline zone is realised in most pegmatites.

This last point, together with the earlier mentioned fact that mineralization of the late albite stage shows the same mineralogical and textural features irrespective of whether outer parts of the pegmatite are in accord with the basic zonal pattern or not, justifies continuing with other late mineralizations, even if direct connections with the basic zonal pattern are very rare. The map by SMIRNOV mentioned above (p. 31) goes a long way toward establishing one such connection.

Pegmatites with Li- and Other Late Mineralizations

Of the remaining late pegmatite-mineralizations the author is personally acquainted only with Li-mineralizations and associated phases through familiarity with the Varuträsk deposit, QUENSEL (loc. cit.). However, there is no need to describe these mineralizations here, for numerous detailed descriptions are found in literature. Instead interest will be focussed on some features believed to be of special significance.

Thus it is noteworthy that the different late mineralizations show varying degrees of combination. Considering lithium- and phosphate mineralizations it is found for instance, that at the Edison Mine, Black Hills, South Dakota, Li-mineralization is dominant, whereas phosphates are rare and mostly represented by apatite and a little lithiophilite—triphyline, no amblygonite is reported, PAGE *et al.* 1953); at Varuträsk, Sweden, both mineralizations are represented, amblygonite, Mn-apatite, and other Mn—Fe—Na—Li-phosphates are present but Li—Al-silicates are very dominant, QUENSEL (loc. cit.); at Viitaniemi, Finland, both Li and P are important, amblygonite (montebrasite) being the dominating phase, and lepidolite is the sole Li—Al-silicate found, VON VOLBORTH (loc. cit.), and finally there exist also pegmatites with abundant phosphate phases but practically no Li-mineralization.

The group of Li-mineralizations and associated phases also shows considerable variation in itself. The Li-content in some deposits is fixed in amblygonite and spodumene as normal but late constituents of the microcline zone near the core margin. In other deposits, however, Li-minerals clearly belong to later zones or fracture fillings and replacement units. As pointed out by QUENSEL (1956, p. 117), relations between Li- and cleavelandite mineralizations may differ markedly in different pegmatite deposits. For instance in Varuträsk, Li-mineralization precedes deposition of the cleavelandite unit, whereas in the Newry pegmatite, Maine, U. S. A., Li-minerals constitute the later stage. A rather special type of Li-mineralization is the frequent occurrence of fine-grained lepidolite rock which may or may not be combined with other Li-phases.

When comparing different Li-deposits one can also find that almost identical mineral associations appear in different stages of the development of the pegmatite bodies. In the Li-bearing pegmatites of the Black Hills, PAGE *et al.* (1953), most of the Li- and Na-mineralization is deposited in zonal units which clearly precede the quartz core, whereas in the Varuträsk deposit and many others, QUENSEL (1956, p. 117, 118), FERSMAN (loc. cit., p. 173—182), LANDES (1925), corresponding paragenetical associations are later than the quartz core, and most of this mineralization occurs as replacement units (which does not imply that they represent subordinate amounts of minerals). This fundamental difference in relation to the quartz core seems to warrant a separate section on the special features of that important pegmatite unit. It will, however, be postponed until a general paragenetical analysis of pegmatite mineralization has been given. Before concluding this section special mention must be made of two papers on Li-pegmatites by STOCKWELL (1933), which in observations as well as in conclusions coincide in many respects with the results of the present investigation. They give a very careful, objective and realistic analysis of mineralization events in this type of mineral deposits.

ORGANISATION OF OBSERVATIONS

Introduction

It is necessary to arrange the observations on mineralization in pegmatites which were given in the previous part into a coherent sequence before they can be properly evaluated and interpreted. This involves considerable difficulties both of procedure and of a conceptual nature. The natural sequence of mineral associations in pegmatites is not always easily determined by direct observation, but has to be deduced from multiple observations and on the basis of various assumptions. Thus Fersman employed a highly complex procedure to establish the crystallization sequence of minerals, and in more recent discussions the genetical order is inferred from the place in the internal zonal arrangement of matter as found in many pegmatite bodies.

Observational and Conceptual Restrictions of Zoning

The basic assumption underlying this modern approach is that zones have developed from the walls inward. A number of arguments which indicate this to be correct have been presented by CAMERON *et al.* (1949, p. 98—104), and this basic assumption is quite generally accepted. It must nevertheless be realized that a zonal unit is a concept in space and not in time, and that this space may be occupied by primary constituents of the zonal unit, earlier minerals projecting into it and much later replacement products, so the ultimate success of that approach rests upon whether these three classes of constituents can always be distinguished. Caution should be applied in the use of the results of zonal analysis in genetical discussions, especially if the analysis has been made for practical (mining) purposes. As an illustration (whether correct or not) of this it may be stated that cassiterite is reported from the intermediate zone, in which microcline perthite is dominant, in many deposits of the Black Hills, PAGE *et al.* (1953). Without doubt the cassiterite is found in the intermediate zone, but one feels tempted to suggest that the mineral has been later introduced into that zone. This would be in better agreement with relations in other cassiterite-bearing pegmatite deposits and it is further supported by the intimate association in the intermediate zone of cassiterite with cleavelandite, PAGE *et al.* (loc. cit., p. 60), which mineral very often is found to penetrate and replace minerals in all earlier consolidated parts of a pegmatite body. Whether all this applies to some minor constituents or not is perhaps still open to dispute. Regarding the major constituents of granitic pegmatite deposits one can however feel confident that the zonal sequence as established by a great number of independent investigations is essentially correct.

Inherent Dualism of Zoning

Even if the last statement of the previous section is accepted one must realize that there exist two entirely different arrangements of zonal units prior to the microcline zone in granitic pegmatites. The recognition of this is believed to be fundamental to an understanding of the genetical problems of these mineral deposits. One zonal arrangement is that outlined by CAMERON *et al.* (1949), it has been widely confirmed and accepted. The other arrangement has been repeatedly described, among others by FERSMAN, BEUS (1951), and SHIBATA (1949). It is the one found in the Stockholm pegmatites and further exemplified in the beginning of the descriptive part of this paper. This second type of internal zoning has been taken as the basic zonal pattern in granitic pegmatites throughout the present paper.

This choice is a logical consequence of the general idea as indicated in the introduction, namely to make an attempt to analyze the natural conditions of mineral deposition in the fields between silicate melts and low-temperature aqueous solutions by starting at the high-temperature—high-concentration end. Whatever special theoretical concepts one may subscribe to, it is in every case more reasonable to assume that a border zone of granitic grain and composition in pegmatites is nearer the high-temperature—high-concentration end and will serve better as a starting point for an endeavour along these lines than a border zone composed of muscovite and quartz.

For technical reasons also this choice of a basic zonal pattern recommends itself, for it is the one most often found in simple pegmatites, and thus has the advantage that the analysis is begun with simple pegmatite systems instead of zonally and mineralogically complex systems, which more often exhibit zoning of the type normalized by CAMERON *et al.* (loc. cit.).

Finally a genetical significance seems to lie in this reasoning, for the simple pegmatites in which the basic zonal pattern is most often found evidently represent primitive stages in the development of granitic pegmatites. This is clearly demonstrated by their systematic poverty in late mineralizations, and by their localization in the central parts of zoned pegmatite districts, cf. FERSMAN (1931, p. 570—575), HEINRICH (1953), VARLAMOFF (1954).

A consideration of systematic contrast in the mineralization sequence within pegmatites thus inevitably leads back to considerations of systematic contrast in the development of the pegmatites themselves.

A Sequence of Pegmatite Types

The same line of reasoning towards increasing complexity which was applied in the selection of a basic pattern of internal zoning may also be applied to the type of mineralization found in granitic pegmatites. Thus, as was earlier stated, muscovite appears in many relatively simple pegmatites with no other con-

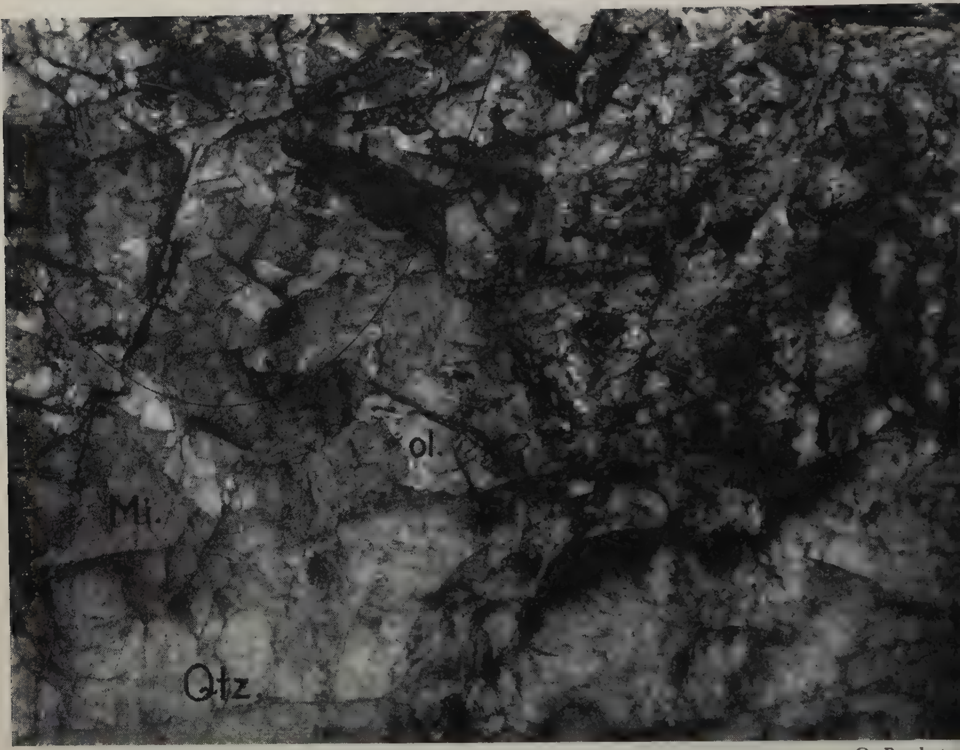


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Fig. 16. Example of a first-stage pegmatite. The pegmatoid zone and the quartz core (Qtz.' actual bottom of the quarry) are seen. Note increasing grain size toward the core and decreasing content of biotite (black) and oligoclase (light grey, ol.), increasing content of microcline (Mi.) in the same direction. Muscovite and late albite are only present in insignificant amounts. 1:100. Ingelsbo, Hestra.

spicuous mineralization; in deposits with late albite muscovite is quite generally found; and in pegmatites with Li-mineralizations both muscovite and late albite are usually present. This is also the order which was followed in the presentation of these mineralizations and their characteristic features.

It is therefore proposed to distinguish four different major stages of pegmatite development in accordance with their increasing complexity. Each of these stages shows a distinct mineralization which is more or less regularly distributed in the zonal order.

The first stage represents the simple pegmatites, which show the basic zonal arrangement and contain plagioclase, biotite, microcline, and quartz as essential constituents. The content of biotite and the An-component of the plagioclase usually decrease away from the walls, Fig. 16. For the rest the sequence is determined by the basic zonal pattern. Example: Pegmatites of Stockholm.

The second stage represents the muscovite-bearing pegmatites. In these biotite and the An-component of the plagioclase are generally less im-

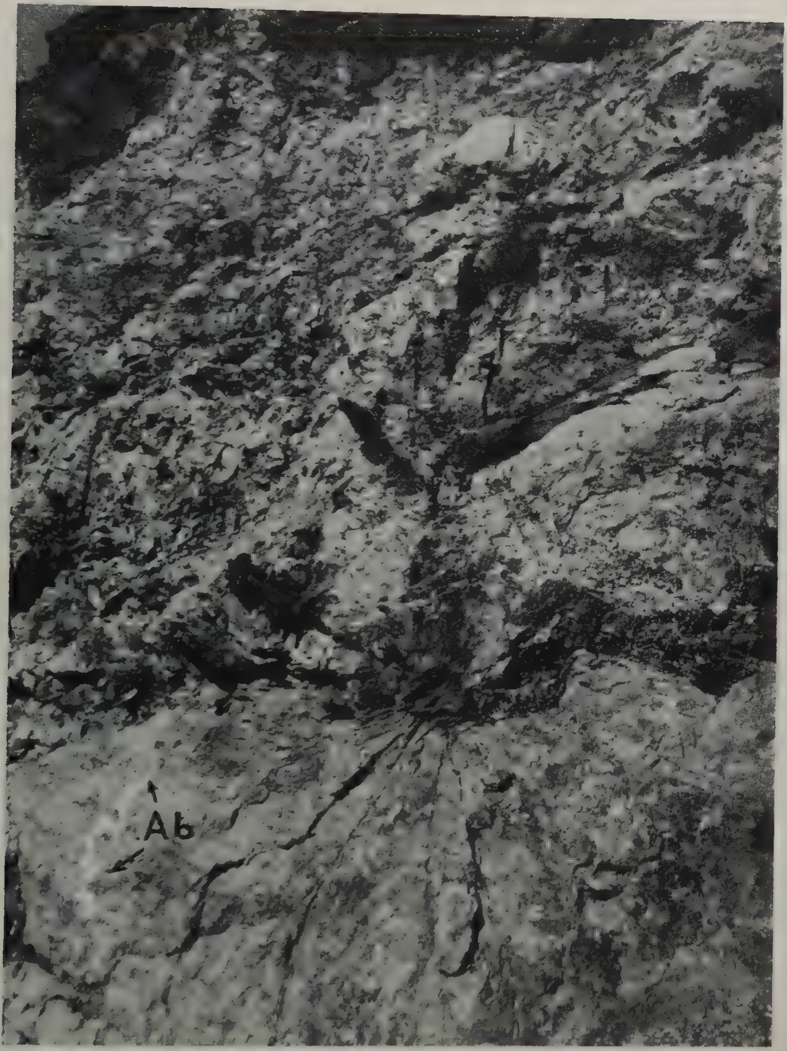

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Fig. 17. Example of a third-stage pegmatite. Northern wall of the Högsbo pegmatite quarry. Hyperite (noritic-amphibolitic) wall-rock at top, outer zones (largely pegmatoid) below, with some dark, disk-shaped xenolites of hyperite in the middle (right). Note the sharp separation of the quartz core (lower field). The core margin is studded with much muscovite (some apparently of replacement origin) and one huge crystal of monazite, (dark lump in the middle, showing diagonal cleavage and being surrounded by radial fissures). Much albite replacement in the pegmatoid zone, just one narrow vein (Ab) in the quartz core. 1:130. 1958.

portant (exceptions occur, cf. Maurice, loc. cit.), and muscovite is an essential constituent. Example: Brattås.

The third stage represents the pegmatites with late albite. Biotite and the An-component are usually further reduced and muscovite is an essential constituent. If the basic zonal pattern is exhibited late albite (or albite—oligoclase) is found, rarely as a primary constituent of the innermost microcline zone and more often as replacement cleavelandite concentrated near the core margin and eventually soaking all outer parts of the pegmatite deposit. Example: Högsbo, where biotite, however, is overrepresented, possibly due to reaction with surrounding hyperite, Fig. 17.

The fourth stage resembles the third, but represents pegmatites with Li-mineralization. This may be represented by different minerals, which characteristically occur in different positions. It seems appropriate to distinguish the following sequence of cases:

a) lepidolite near the core margin or in association with late albite;

b) amblygonite and/or spodumene-petalite as replacement products or almost equivalent amblygonite/spodumene-quartz units;

c) amblygonite and/or spodumene as primary constituents of the core margin and the innermost microcline zone.

Of these a) corresponds to the Li-mineralization of least intensity, and may often be found in deposits where b) and c) are lacking, cf SUNDIUS (1952), OFTEDAL (1942).

Example of the fourth stage: Varuträsk.

The special caesium mineralization manifested in the formation of pollucite has been omitted in this presentation for the sake of simplicity, it evidently marks an additional stage in the complication and development of granitic pegmatites.

In the later stage pegmatite deposits outer zones with increasing frequency deviate from the basic zonal pattern and are in accordance with the sequence given by CAMERON *et al.* (loc. cit.).

Comments

This sequence of major constituents calls for some comments. It is reminiscent of the classification of replacements in granitic pegmatites as given by GEVERS *et al.* (1937, p. 48—49), but there the sequential aspect is not explicit, whereas in the present sequence no restriction to replacements is intended. It further does not run entirely parallel with the crystallization sequence as given by FERSMAN (1931, Figs. 64, 65), or with the sequence of mineral assemblages given by CAMERON *et al.* (loc. cit.). This is because those sequences refer mainly to trends within pegmatite bodies, whereas the present sequence primarily denotes trends in the development of granitic pegmatites as manifested in differences in mineralization between different individual deposits. The new minerals of later stages in more complex deposits do not necessarily take their place after the earlier ones in the crystallization sequence or in inner units of the zonal sequence. The deviation from Fersman's principles is perhaps best illustrated by lepidolite, which is already found in the earliest types of the fourth stage, that is in those deposits with a weak Li-mineralization only, but in pegmatites with a strong Li-mineralization it is often the last Li-mineral to form. Further muscovite may well crystallize before microcline, in spite of the fact that microcline is also found in simple pegmatites and thus belongs to an earlier stage than does muscovite. Likewise spodumene and amblygonite as primary minerals in the inner part of the microcline zone in most deposits precede late albite (cleavelandite) in crystallization and zonal sequence. It seems highly significant that later mineralizations (except muscovite) in most cases are localized between the quartz core and the microcline zone. The mineral sequence in pegmatites thus poses two problems, the problem of sequence between types of pegmatites and also the sequence of mineral formation in pegmatite bodies.

It is advantageous in two respects to focus the emphasis of this type of discussion or in a classification of granitic pegmatites on the sequence of the major mineral constituents as it has been done here. It gives an outline of the development of granitic pegmatites, which is believed to be of rather general applicability, and it also gives the most reliable picture of the changes in the bulk chemistry of the pegmatite system. The occurrence of the accessory pegmatite minerals will be considered in a following section. Be it enough to state here that regional variations in their distribution are too large to permit the establishment of a generally applicable sequence or classification based on their occurrence. Tourmaline, for example, is a very common accessory, and has been included as a key mineral in pegmatite classifications by Fersman, Niggli, and others. However, in some regions, e.g. the Belgian Congo, it is found already in pegmatites of the first stage, cf. VARLAMOFF (1954), and in others, e.g. S. W. Sweden, it is not found even in those of the third (and fourth) stage. Again variations in the chemistry of the pegmatite system are not always truthfully depicted by variations in accessory minerals. For instance changes in the composition of tourmaline as a function of the zonal and paragenetical position of that mineral, STAATZ, MURATA, and GLASS (1955), would indicate that the activity of the potassium ion increases during the development of a pegmatite body, and reaches its highest value during that late stage when microcline is replaced by albite! Likewise, by similar reasoning one would find from the sequence of cations in Ta—Nb minerals that the calcium-ion reaches its maximum activity during the lepidolite stage when microlite often is deposited, which clearly is contrary to relations in the phosphate and alumosilicate minerals. These divergencies probably arise from the intricate laws which govern the distribution of cations between competitive anions in a complex system, which is, however, in the case of pegmatites, dominated by the alumosilicates. The relations of the dominant phases find their expression in the sequence of major constituents given above.

Sequence of Paragenetical Groups

The sequence given in the previous sections is a construction on the basis of increasing complexity in pegmatite deposits. It is thus an artificial attempt to distinguish four major stages in the assumed development of an essentially continuous spectrum of pegmatite types. In spite of its artificial nature it is believed to be of some truly geological significance because of analogies with the distribution of pegmatite-types in clearly zoned districts and with sequences of internal zones in pegmatite deposits, both of which tend to strengthen the inherent assumptions. It is a prerequisite to the next step, namely a division of minerals in granitic pegmatites into paragenetical groups, for the mineral compositions of these vary somewhat according to the type of the deposit.

On the basis of field-observations relating to characters in texture, main mineralogical composition, and position in the framework of internal structure in pegmatites, the following paragenetical units have been distinguished, in order of their formation within individual deposits:

1) Granitoid (border) zone,
2) zone of graphic granite,
3) pegmatoid zone,
4) core margin,
5) alkali-replacements,
6) core margin mica and
7) alteration products.

In this sequence overlapping between units 3 and 4, and also between units 5 and 6 is sometimes observed. Deviating types of outermost zonal units, as earlier discussed, have been omitted from this list, and so have some minor late groups e.g. banded aplitic rock, mineral associations in cavities, and carbonate—sulphide associations. The quartz core likewise has been omitted, this was done because its proper place in the sequence is difficult to assess. On detailed analysis additional groups and many subdivisions can probably be established, but the seven groups given above, together with the quartz core, seem to be sufficient for the present outline to represent mineralization in pegmatites and they will be the main subject of later interpretation.

Characterization of Paragenetical Groups

The granitoid zone and the zone of graphic granite need no further comment here, but the pegmatoid zone constitutes a more variegated paragenesis.

The Pegmatoid Zone

As it is here conceived the pegmatoid zone begins at the point when graphic granite ceases to form. Where that unit is lacking or only represented by scattered crystals difficulties arise in delineating the pegmatoid zone from the inward coarsening granitic border. Ideally the pegmatoid zone should be free from quartz other than interstitial core quartz, which strictly speaking likewise does not belong to its paragenesis. A concentration of quartz is often seen at the outer border of the pegmatoid zone. In many pegmatites the zone is rich in plagioclase and biotite. The content of these constituents systematically decreases inward, cf. Fig. 16. Plagioclase (other than albite) may even dominate this zone in some pegmatite deposits or in certain localized parts of them, and then microcline is found in the next group, the core margin. In most cases, however, microcline is the dominant phase of the pegmatoid zone, which then constitutes a microcline zone proper.

The variation in the pegmatoid zone due to the type of pegmatite is quite

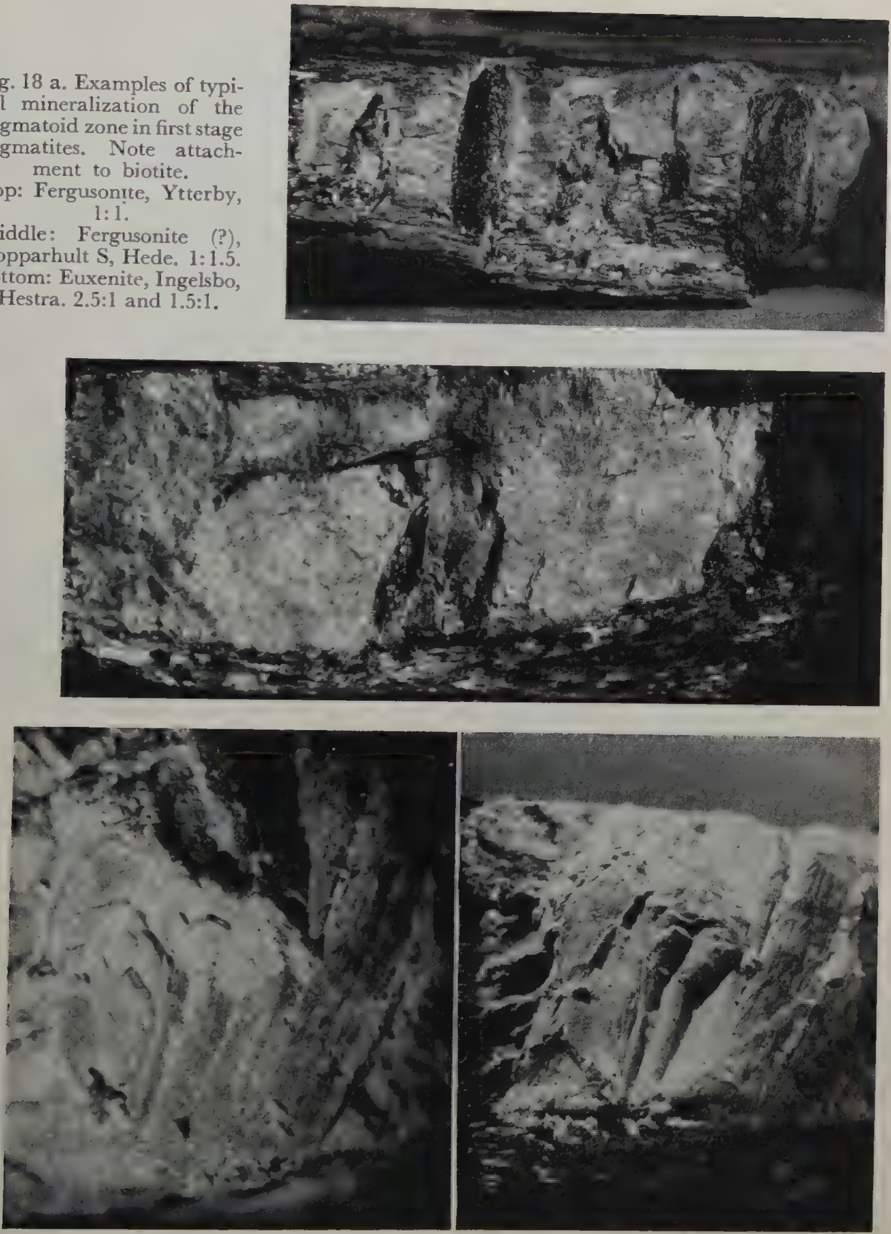

Fig. 18 a. Examples of typical mineralization of the pegmatoid zone in first stage pegmatites. Note attachment to biotite.
Top: Fergusonite, Ytterby, 1:1.
Middle: Fergusonite (?), Kopparhult S, Hede. 1:1.5.
Bottom: Euxenite, Ingelsbo, Hestra. 2.5:1 and 1.5:1.

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marked. Thus the microcline itself seems to vary systematically in colour, it is deepest red in first stage pegmatites, and is almost white in the fourth stage. Amazonite apparently sometimes characterizes stages in between the third and the fourth. Characteristic mineralization preferentially found in the pegmatoid zone of first stage pegmatites comprises titanite and allanite, often occurring together with oligoclase, and ilmenite, magnetite, Y, Ta, Nb minerals, gadolinite,

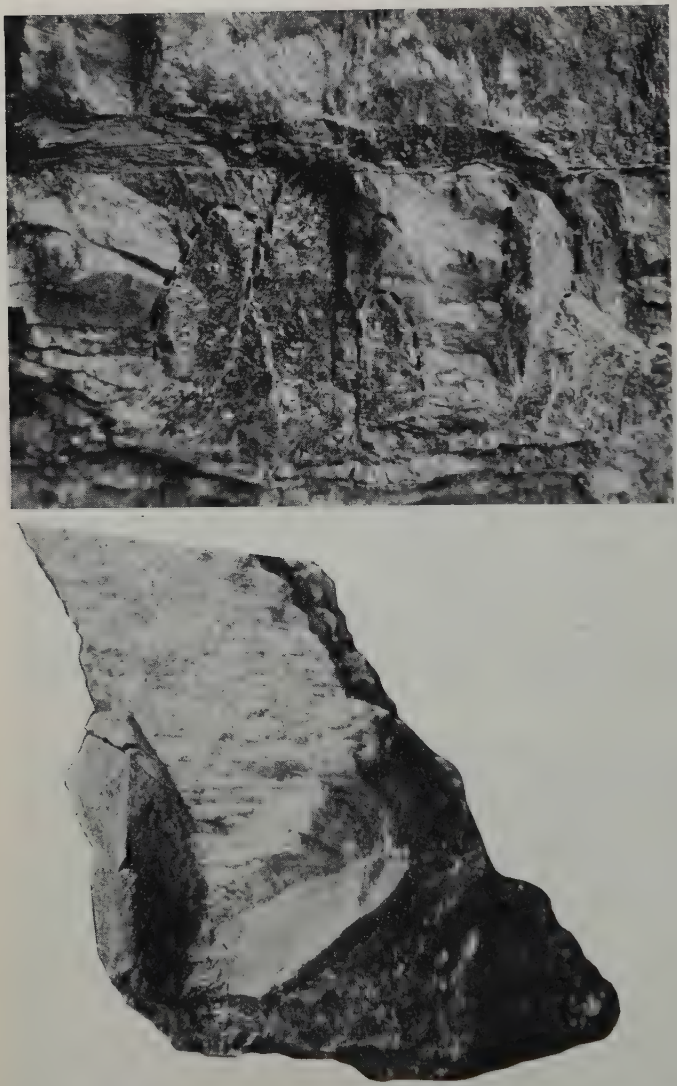

Fig. 18 b. Fergusonite-like minerals grown on biotite.
Top: Apparently tetragonal crystals with high-order pyramids typical of fergusonite. Routivare W, Jokkmokk 2:1.
Bottom: Multiple twins of lower symmetry. Routivare E. 2.5:1.

O. B. coll. & phot.

zircon, monazite, xenotime, and thorianite—uraninite, often grown on or between flakes of biotite, Fig. 18. In a few cases, which were observed in situ by the writer, this particular mineralization was found in the microcline zone, but within the reach of the core quartz.

In later-stage pegmatites the pegmatoid zone offers less interest. In the second stage muscovite is a characteristic accessory, allanite in slender prisms may be found in the outer parts, and tourmaline, blue-green apatite, and beryl in the inner parts. Y, Ta, Nb minerals are sometimes found as rarities in this environment and so is columbite—tantalite. In the third stage the same minerals occur, but allanite tends to be rare. In the fourth stage, substage 4 c, spodumene and amblygonite may participate in the paragenetical group of the pegmatoid zone.

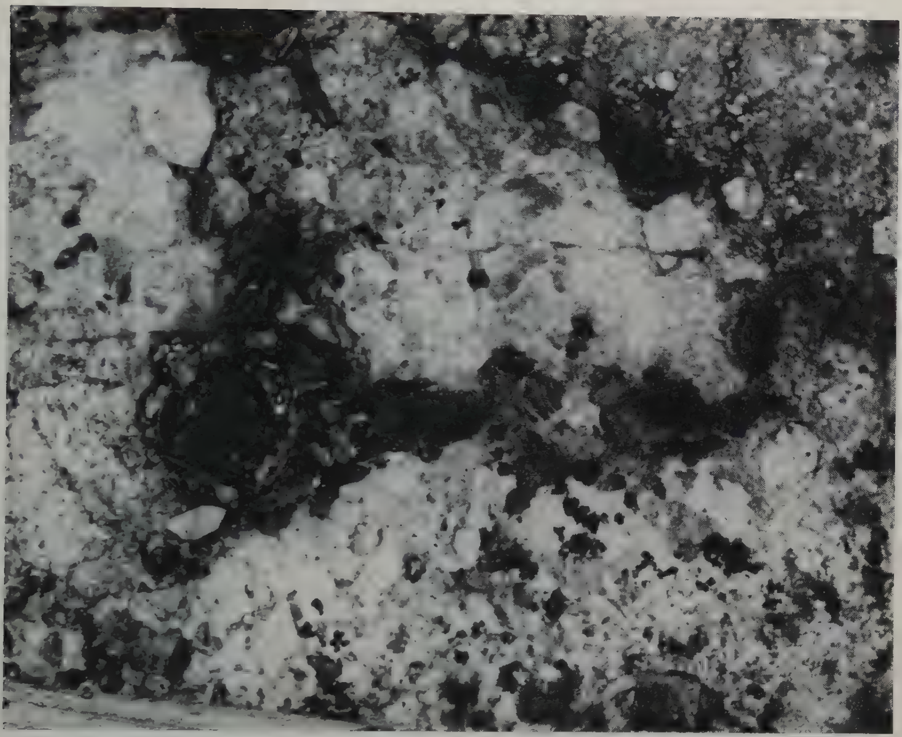

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Fig. 19. Concentration of dark minerals: Tourmaline, garnet and muscovite; in the core margin of a small, second-stage pegmatite. Note the microcline-rich pegmatoid zone which is surrounding the core margin. The outer zone of graphic granite is also seen (bottom). The quartz intergrowths of this unit are seen as short, dark grey, straight rods above the head of the hammer (lower right corner). Ryssberget, E of Skellefteå. 1:3.5.

The Core Margin

The core margin as here conceived embraces the transition zone between the core and the pegmatoid zone. It is marked by the appearance of individual crystals which project into the quartz core from the pegmatoid zone or are entirely surrounded by quartz. Thus the minerals belonging to this group are always found combined with quartz. As mentioned above microcline is one of the prominent phases taking this position, but for chemical reasons it is sometimes favourable to restrict the concept of the core margin to minerals which form after the growth of microcline had ceased.

In pegmatites belonging strictly to the first stage biotite is found in this position, sometimes also sulphides such as pyrite, pyrrhotite, and molybdenite. In others, which show transitions to the second stage, muscovite, beryl, and tourmaline are sometimes found here in minor amounts. These are, however, first typical in the core margin of second stage pegmatites, Fig. 19, and here beryl and muscovite often occur in quantities of economic importance, occasionally together with minor columbite—tantalite, apatite, and others. In the third and fourth stages the same minerals are found, together with triplite and

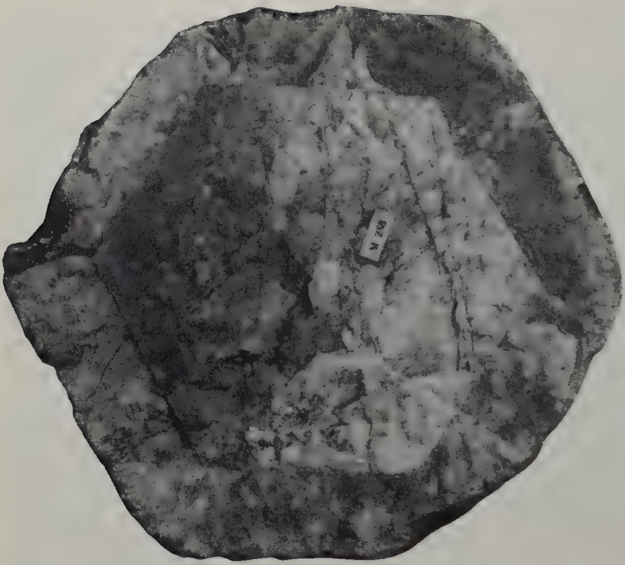

Fig. 20. Beryl surrounded by a mantle of cleavelandite, 1:1.5. Kisko, Finland.

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Coll. of University of Stockholm.

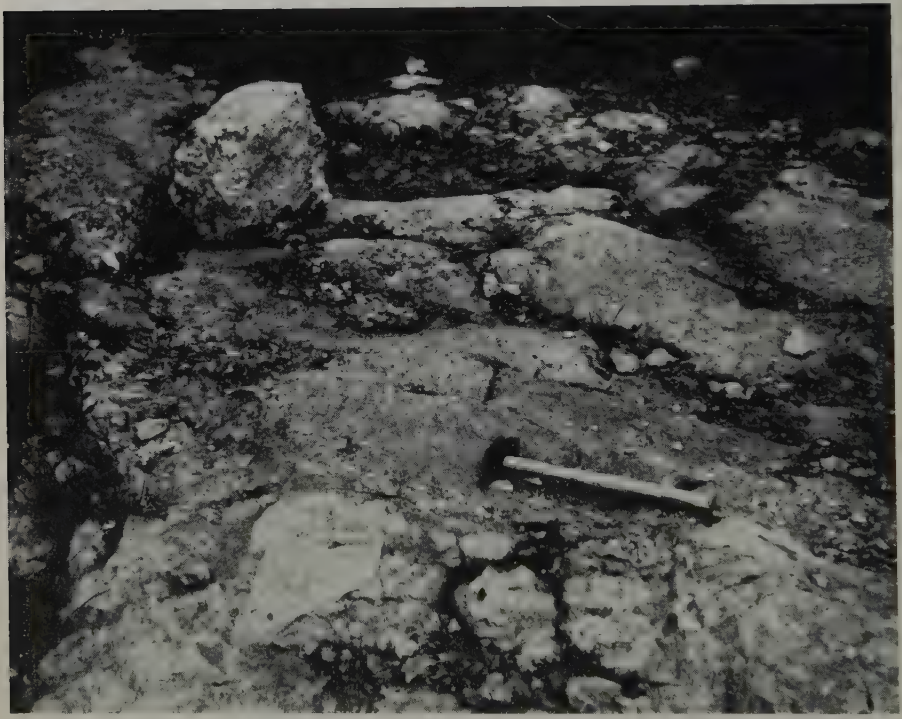

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Fig. 21. Sugar-grained albite-rock of circular area replacing the pegmatoid zone (note the large microcline crystal). The margin of the albite-rock is marked by a seam of coarse lepidolite crystals, which can be followed from below the hammer to the upper left corner by their bright reflexes. Blue tourmaline, manganese apatite, löllingite and cassiterite are minor minerals in this paragenesis. 1:15. Varuträsk.

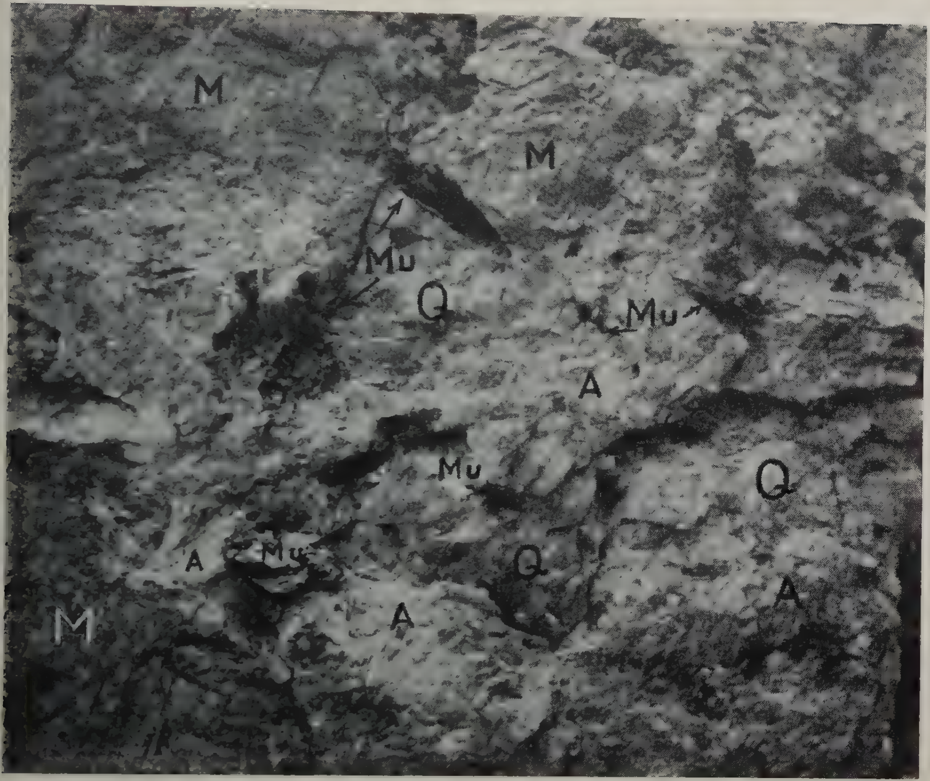

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Fig. 22. Late plagioclase (cleavelandite) (A), and muscovite (Mu), replacing giant crystal of microcline (M), along margin of a fracture-filling offshoot from the quartz core (Q). Main quartz core is to the right, outside the photograph. It may be noted that the deposit actually is a typical example of the first stage, and features as shown are highly localized exceptional phenomena. 1:7. Kopparhult S, Hede.

monazite in the third stage and spodumene and amblygonite in the fourth stage.

The Alkali-replacements

The paragenetical group of alkali-replacements is by definition limited to pegmatites of the third and fourth stages. As discussed by Cameron *et al.* (1949, p. 88—91), replacement often is difficult to establish beyond doubt. It is believed that many features often described as involving replacement can by equally good reasons be considered as due to any one of the following processes: consolidation-reaction, simultaneous growth, overgrowth, and inclusion. However, post-consolidation replacement of microcline by muscovite—albite, or by petalite and spodumene is so obvious in many deposits that it cannot be denied. These replacements often are seen to cut across the inner zonal units and reach the microcline zone, and it is here that replacement is most intensively and clearly manifested, whereas other minerals, such as beryl, tourmaline or columbite often are just surrounded by the newly formed phases, cf. Fig. 20. Quite generally core margin minerals seem to be relatively stable, and often continue to form in this paragenesis, with slightly changed habit. Thus coloured tourmaline and colourless, vitreous, tabular beryl are found here. Cassiterite is a characteristic accessory of this paragenetical group, it is most closely associated with albite (cleavelandite) in pegmatites of the fourth stage.

As described by many investigators, e.g. Fersman (1931, p. 256, 257), albite often is found in two modifications, namely as sugar-grained masses or as cleavelandite. This has also been described from Varuträsk, cf. Quensel (1956, p. 79). Other Swedish occurrences where both modifications can be observed are Högsbo, Skuleboda, and Utö. As a rule the sugary form is earlier than cleavelandite. The sugar-grained albite, furthermore, is often found in well defined vein- or dyke-like masses and in pipe-like bodies, cf. Fig. 21, whereas cleavelandite usually is found in irregular strings of crystal clusters and erratic cauliflower-like bodies, Fig. 22. Both types are quite often accompanied by mica, in third-stage pegmatites most often represented by muscovite, in exceptional cases also by lepidolite, and in fourth-stage pegmatites lepidolite is the rule. Sugar-grained albite is often associated with small garnets.

Spodumene is the most common Li-replacement mineral, and it seems that petalite is only formed in cases of very intense Li-mineralization, and it is a much rarer mineral. Apart from these cation exchanges in alumosilicates considerable exchange of cations in other compounds, such as the phosphate minerals, takes place concurrently.

The Core Margin Mica

The paragenetical group of the core margin mica comprises a highly characteristic formation in many pegmatites. Usually there are found localized masses of fine- to medium-grained rock, dominantly composed of mica and quartz, occasionally plagioclase, garnet, and even topaz may become important constituents. There exist all transitions between this development and that of ordinary large books of mica, which often are found concentrated along the core margin, and belong to that paragenetical group.

The position taken by the paragenetical group of the core margin mica in the general sequence seems to be somewhat indeterminate, thus in some pegmatites it is directly related to the albite replacement (Högsbo), in others it is in part clearly younger (Skuleboda), in Varuträsk it is affected by later cleavelandite formation, Quensel (1952, p. 57, 61), and from the pegmatite map by Smirnov presented by Vlasov (1955, Fig. 1), it is evident that two types of core margin mica developed in that particular deposit. The one is made up of muscovite and precedes most Na—Li mineralization, and a second type is composed of lepidolite and is essentially later than most Na—Li mineralization. However, the general impression from a number of descriptions is that the core margin mica is a late group in granitic pegmatites, marking a concluding phase in the development of core margin assemblages in second-stage pegmatites (muscovite), and also as a rule later than sugar-grained albite replacement in third stage pegmatites (muscovite and sometimes minor lepidolite). In fourth stage pegmatites the formation of lepidolite rock likewise seems to follow upon the de-

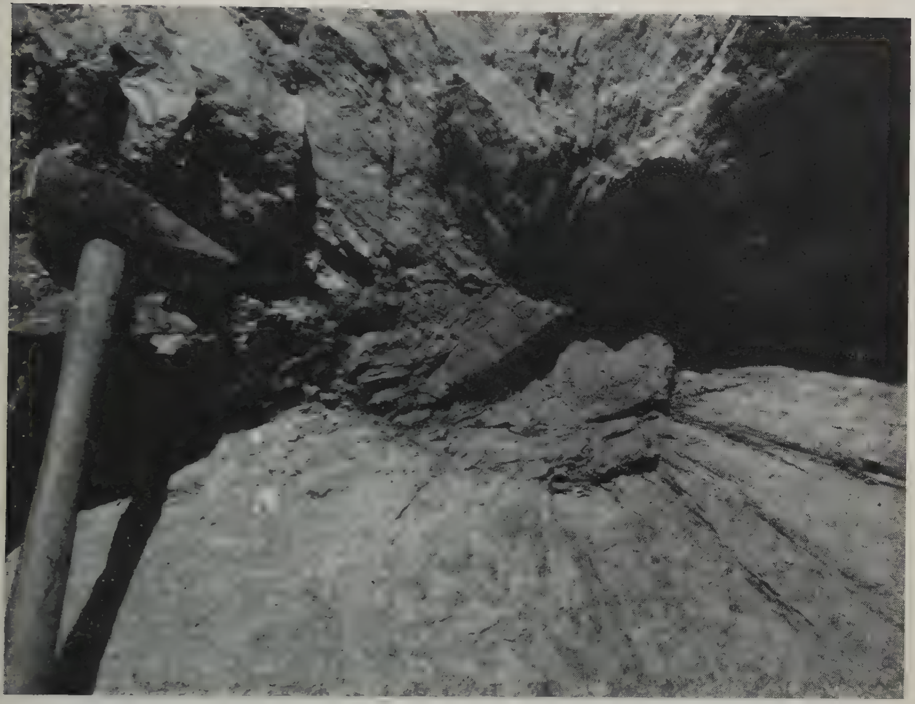

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Fig. 23. Crystal of monazite at the core margin, projecting into the core-quartz (bottom), and developing its own crystal faces. 1:5. Högsbo.

position of most spodumene and petalite, whereas cleavelandite formation may evidently go on also after the deposition of lepidolite. If this is correct it denotes a splitting up of the core margin mineralization, for in pegmatites of the first and second stage the core margin represents essentially one uniform group, of which muscovite is an important and very common constituent, but in later-stage pegmatites this uniform group is split up into a first group preceding the Na—Li-mineralization of these stages, and a second group, the group of the core margin mica, which follows upon culmination of that phase.

Regarding additional minerals which belong to the paragenetical group of the core margin mica one must state that this group is not markedly multiphased. Perhaps it has not been adequately studied, for evidently these granular micaceous masses are not as attractive to mineralogists as other paragenetical groups, where large and/or well crystallized specimens may be secured. Most important and characteristic accessories, which sometimes offer economic possibilities, are cassiterite, tantalite, and microlite. Samarskite and similar minerals may also be found here. Minor amounts of sulphides, such as arsenopyrite, pyrite, and also sphalerite have been noted in this association. Tourmaline and beryl are frequently to be found.

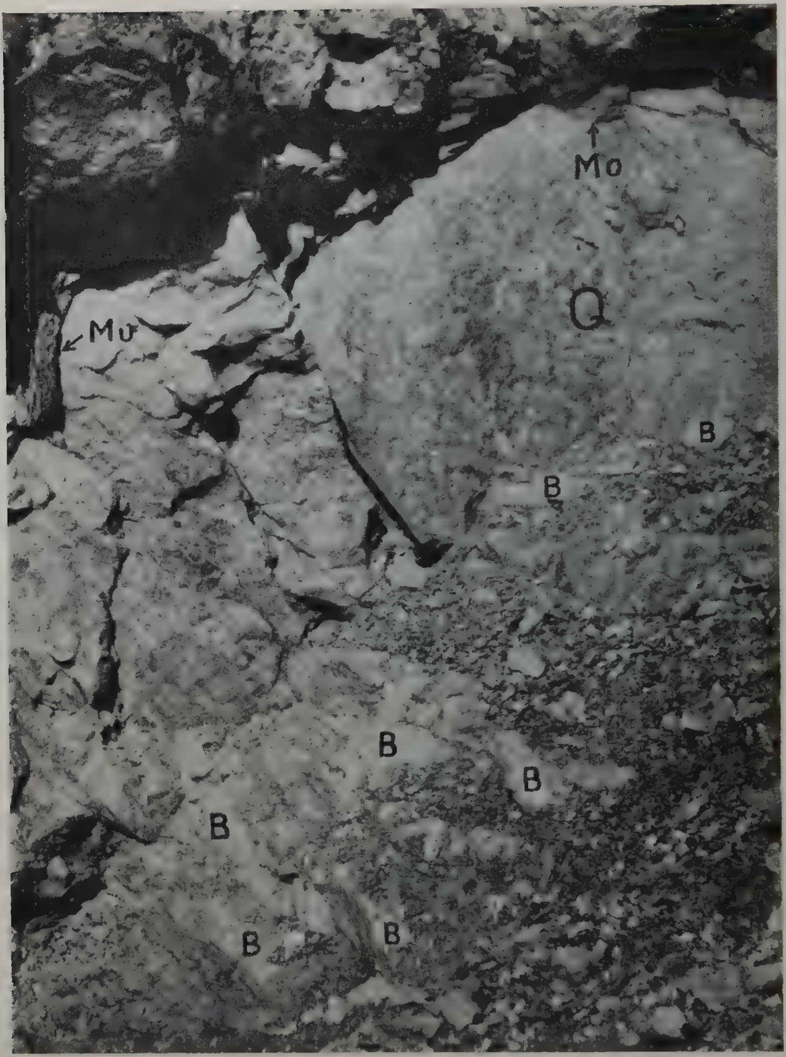

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Fig. 24. Much beryl (B), in the quartz core near the core margin, which is studded by crystals of monazite (Mo), and muscovite (Mu). Note bending of muscovite crystal at the extreme left. The beryl crystals are surrounded entirely by quartz, (Q), which evidently was able to support their weight and growth, 1:20. Högsbo.

Alteration Products

Late alterations, which constitute the seventh paragenetical group of this paper, will be considered only briefly. It is rather heterogeneous and comprises the late formation of sericite, chlorite, clay minerals and other "low temperature" phases. These have been observed in a great number of pegmatite deposits, and in many instances it has been possible to prove that these products were formed endogeneously and without any relations to surface- or near-

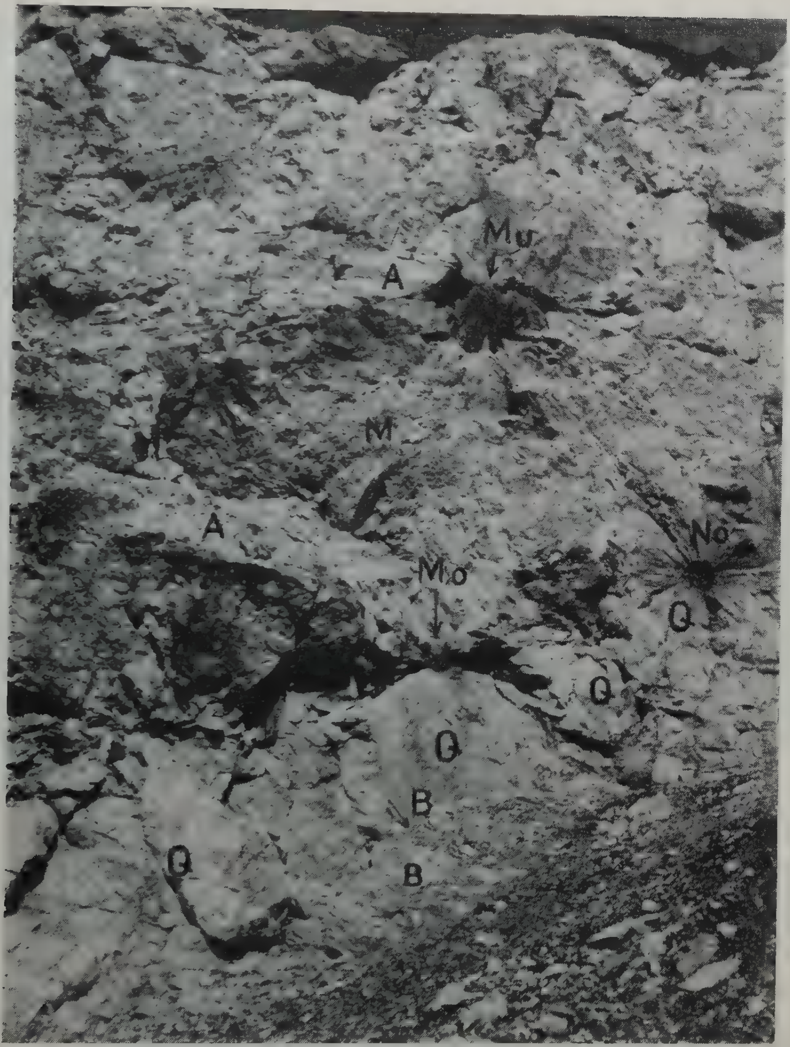

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Fig. 25. General view of relations at the site of figs. 23 and 24. Microcline (M) of the pegmatoid zone is sharply separated from the quartz core (Q), and veined and replaced by albite (A) and muscovite (Mu). Monazite (Mo, No) at the boundary between the core and the pegmatoid zone, core margin. Beryl (B) in the core-quartz. 1:100. Högsbo.

surface agencies. In many respects, however, these late alterations resemble products of normal weathering.

The Relations of the Quartz Core

A core of quartz is a most common feature of both simple and complex pegmatites. As a rule it is found near the centre of the pegmatite body. One can often observe the way in which minerals from the surrounding zones, such as biotite, microcline, beryl, tourmaline, monazite, and amblygonite project into

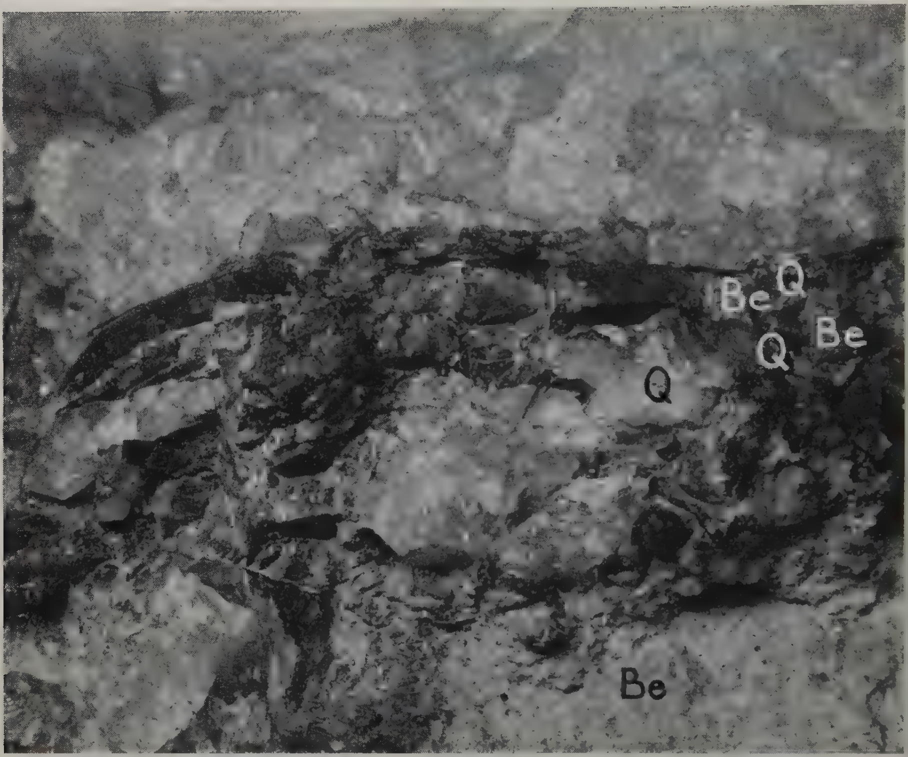

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Fig. 26 a. Bent and broken beryl crystals in core-quartz. Note the quartz-filled fracture Q—Q, which offsets a beryl Be—Be. 2:1. Högsbo.

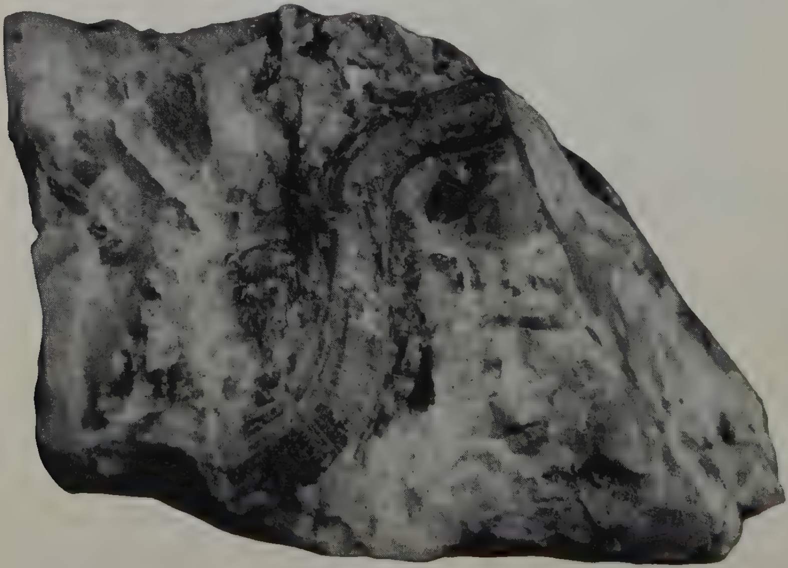

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Fig. 26 b. Bent and broken tourmaline crystal in quartz with some cleavelandite. 1:1. Varuträsk.

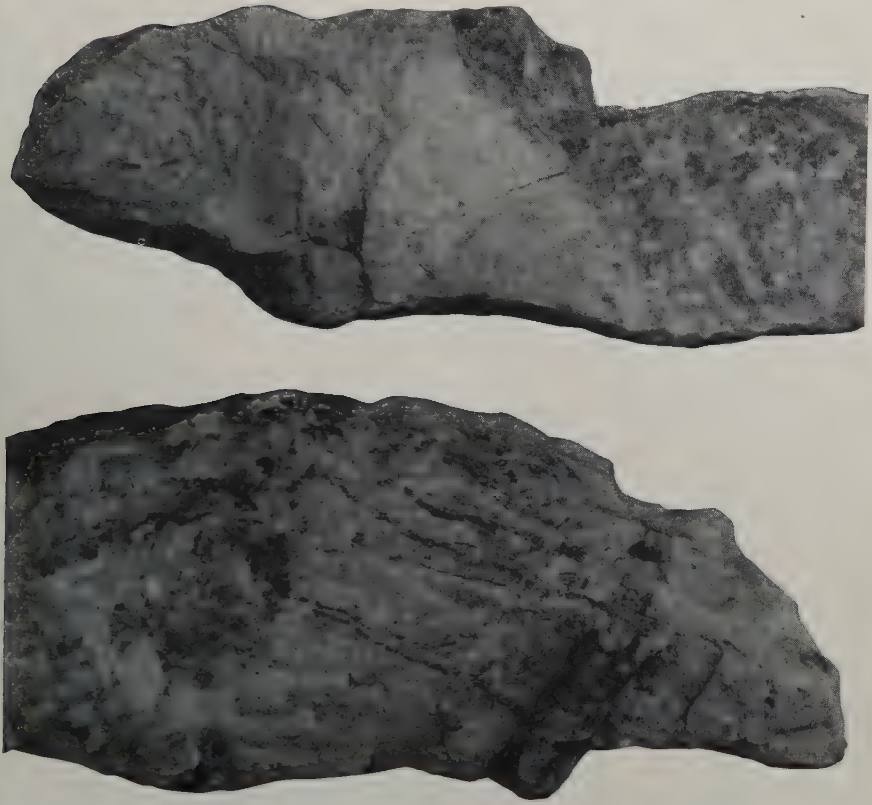

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Fig. 27. Beryl crystals surrounded concentrically by radial cleavelandite in core-quartz. 1:1.8. Högsbo. Transverse section (top), and longitudal section (below). Note fracture-fillings of quartz in the cleavelandite and in the beryl crystal. Relations may be taken to indicate that the beryl acted as a growth-centre for the cleavelandite, and that the quartz was able to support the beryl crystal and permit the accretion (by diffusion?) of the cleavelandite prior to its own consolidation. Cf. Fig. 20 and Hess (1933a, Fig. 3, p. 533).

the quartz core and more or less perfectly develop their own crystal faces in it, cf. Figs 19, 23. Sometimes single crystals of this type seem to be surrounded entirely by quartz, Fig. 24, 25.

Similar relationships are also seen in some individual fracture-filling units within the pegmatite bodies.

These observations are not entirely sufficient for a decision on relative age. Most investigators consider them to indicate that quartz is the later phase, but some workers, e.g. Heinrich (1948, Fig. 13), without further evidence, hold that the quartz is replaced by the other minerals (tourmaline in that specific case).

In many instances these euhedral crystals are bent, fractured or broken, Fig. 26, whereas the quartz shows no corresponding signs of deformation and it even fills the cracks and fractures in the crystals. In extreme cases fractures filled by core quartz reach far into outer zones, cf. Fig. 5, and also may transsect the wallrock, cf. CAMERON *et al.* (loc. cit., p. 70—83). In these cases the quartz is definitely later.

In other instances the same textural relations with euhedral crystals of amblygonite, cf. VON VOLBORTH (loc. cit., Fig. 7), cleavelandite, cf. QUENSEL (1956, Fig. 58), and other minerals in quartz are found, where the distribution of these minerals seems to have been controlled by fractures or zones of weakness, of which not even traces can now be seen.

Clearcut fracture-fillings may also be found within the quartz core. In such cases the special texture indicated above may be found only at the fringes of the fracture-filling bodies, and all gradations between knife-sharp contacts and irregularly dispersed porphyroblast-like crystals of the type described in the former section seem to exist. An unusually illuminating illustration, showing these gradations in one single mineral-shoot is given by VON VOLBORTH (loc. cit., Fig. 8). It should be noted that the development of crystal faces is found almost exclusively when the surrounding material is quartz.

Both from descriptions of single deposits, cf. QUENSEL (1956, p. 92), and a study of many pegmatite quarries and maps it becomes evident that the quartz core is generally not very extensively mineralized, even if later fracture-fillings and replacement-masses are very important in the other parts of a pegmatite deposit. Furthermore, these mineralizations are often found confined to the outer parts of the quartz core, near the core margin. Many illustrative diagrams showing these relations have been published by SHIBATA (1949, 1952), who considers the cleavelandite stage to precede the formation of the quartz core, cf. also Fig. 27. Many investigators of pegmatites, e.g. GEVERS *et al.* (1937), have stressed the apparent correlation between specific mineralizations and the occurrence of a quartz core. This is amply illustrated by those cases in which the quartz core is surrounded by albite- or Li-mineralization, which replaces outer zones. It seems almost unnecessary to point out that in most cases (as in relatively simple pegmatites) quartz cores are not accompanied by any specific mineralization at all.

Variations in Crystal Size in the Paragenetical Groups

Before concluding this short survey of the features of paragenetical groups in granitic pegmatites, attention must also be given to variations in crystal size. Crystal size actually is one of the fundamental properties which define petrographically the pegmatites as a group, and indeed, many genetical problems of pegmatites are problems of crystallization. It is therefore adequate to note that in passing from the marginal granitoid zone to the core margin, there is a gradual increase in crystal size, which reaches a maximum in, or near, the core margin, and is manifested in giant crystals of microcline, beryl, tourmaline, amblygonite, and spodumene. In the earliest alkali-replacement, the sugar-grained albite, crystal size is again at an extreme low, whereas in later replacement units it increases a second time.

Core margin micas (as a separate group and not as constituents of ordinary core margin assemblages) generally are of medium and fine grain, and the latter is true especially of the late alteration products.

Synopsis of Mineralization in Granitic Pegmatites

A diagrammatical synopsis of the essential content of preceding sections is presented in Fig. 28. As such it is even more schematical than the above paragraphs and its main purpose is to bring out the two-dimensional arrangement of mineralization according to type of pegmatite deposit and paragenesis. This means that different minerals occupy analogous paragenetic positions in pegmatites of different types.

This diagram definitely does not pretend to do justice to the complicated pictures of chemical, paragenetical, and mineralogical relations between, and in, different pegmatites with their wide range of variation, but, as stated before, it is intended only to give an outline of mineralization in granitic pegmatites. The realization of this purpose is further considerably limited by various factors. One of the most important of these is the difficulty experienced in including observations from literature, because these often were made from different starting points regarding fundamental assumptions, observational technique, and paragenetical subdivision. The presentation is therefore based mainly on evidence from localities which the writer has been able to visit and others where published descriptions gave him considerable confidence in the recognition of the paragenetical groups.

Many paragenetical groups, or variants of such, which may even be of great local importance, or scientific interest, e.g. quite wide-spread groups with fluorite and other fluorides; the cryolite paragenesis of Ivigtut, bismuth-mineralizations in Namaqualand; a molybdenite—apatite—zircon—uraninite mineralization near Vittangi, Sweden, and many others; have been excluded, for it was believed that they are not of direct and general significance for genetical aspects, and also because of insufficient personal knowledge on the writer's part.

When judging the indications on the occurrence of accessories which have been given, it must further be recalled that these are mere examples, believed to be more or less typical of the paragenetical group and pegmatite stage where they are found. As already exemplified with the variations in the occurrence of tourmaline, the localization of minor minerals may vary greatly. Quite generally the occurrence of accessories may vary from the extreme case where the mineral in question is not found at all in a deposit to the other extreme, where it is found in great quantity in much earlier paragenetical surroundings than usual. Important columbite deposits in granite furnish a striking example of the latter case. The diagram is thus intended to express the relations which prevail most often, but since there are no means at present to settle objectively such matters of frequency, bias from subjective sources may be involved. On the other hand do the limitations from personal experience also involve a certain strength, for the diagram thus largely represents relations as actually found in a limited number of deposits and not a statisti-

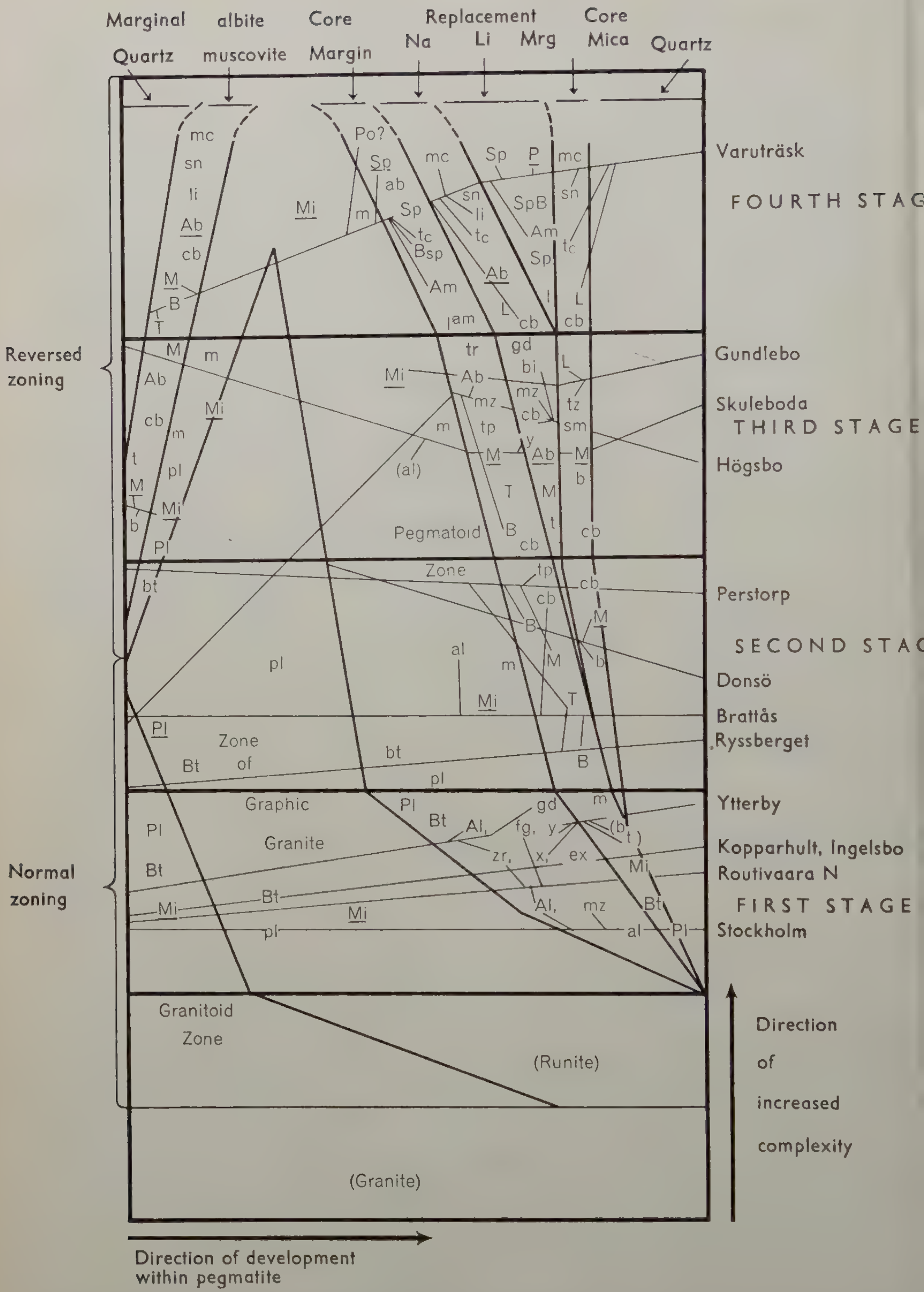

Fig. 28. Schematical synopsis of mineralization of zoned granitic pegmatites. Represents paragenetical relations of thirty typical pegmatite minerals, cf. text. Course of development and mineralization of a number of Swedish pegmatites (as far as can be established on present exposures) are especially indicated. The sequence of paragenetical groups in the development

cal synthesis, with its risk of loss of discrimination and significance, as pointed out already in the preface.

Minerals which quite generally seem to occur in almost all paragenetical groups, such as garnet and pyrite, have been excluded from the diagram. On the other hand minerals, which quite distinctly are found in a limited number of paragenetical positions, enter the diagram in more than one position. Monazite is thus found in the paragenesis of minerals grown on biotite in the pegmatoid zone of first stage pegmatites, and also in the core margin and albite replacement groups of third stage pegmatites. However, from this arises another difficulty regarding some minerals, which are found predominantly in one paragenetical group but also occur in others, for this again requires a kind of quantitative estimate. For instance Y, Ti, Ta, Nb minerals are indicated primarily in the pegmatoid zone of first stage pegmatites, even if it is well known that they are also sometimes found in connection with albite-replacement. A generous indication of all possible or reported localizations would completely obscure very real trends. Already with the present form of the diagram the predominant rôle of Y, Ti, Nb, Ta minerals in early stages of Fe, Mn, Nb, Ta compounds in intermediate stages and Ca, Nb, Ta-compounds in very late stages is not easily perceived.

In spite of these severe limitations of the validity of the paragenetical diagram it should serve well in clarifying the approach of this paper, and also in providing a somewhat simplified and generalized picture for the later attempt to interpret features of mineralization in granitic pegmatites. However, for such an endeavour, mineralogical observations alone are not sufficient, and must be supplemented by observations from other fields. A brief presentation of some of these auxiliary aspects is therefore given in the next sections.

AUXILIARY ASPECTS

Exchange of Material with Host Rock

The question of the rôle and extent of the exchange of material between pegmatite bodies and host rocks has been a subject of controversy for a con-

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within pegmatite generally concurs with the spatial sequence from the wall inward. Alkali-replacements are exceptions to this and invade outer zones. The Li-replacement at Varuträsk precedes the Na-replacement, but this seems to be a deviation from the order commonly found. In this respect the present diagram represents data from literature. Alteration products have been ignored.

Key to symbols of minerals:

ab = albite
al = allanite
am = amblygonite
b = beryl
bi = bismuth
bt = biotite
cb = columbite
ex = euxenite
fg = fergusonite
gd = gadolinite
l = lepidolite
li = lithiophilite
m = muscovite
mc = microlite
mi = microcline
mz = monazite
p = petalite
pl = plagioclase
po = pollucite
Quartz
sm = samarskite
sn = cassisterite
sp = spodumene
t = tourmaline, c = coloured
tp = triplite
tr = triphyline
tz = topaz
x = xenotime
y = yttrotantalite
zr = zircon

$\underline{M}$ = dominant
M = important
m = common
(m) = rare

siderable time and is far from settled even now, cf. JAHNS (1955, p. 1058—1067). However, the completely overwhelming number of reported cases of pegmatites of a bulk composition near granite or granodiorite, which are found to occur in a wide variation of host rocks, including crystalline limestone and dolomite, quartzite, mica schist, granite, gabbro, metamorphic effusive rocks and so on, draws a definite limit for the possible rôle of such an exchange, as does the fact that major variations in composition within those limits, such as extensive Li-, Ta-, Nb-, Sn- or Be-mineralizations, cannot be successfully correlated with relative concentrations of these elements in the host rocks. On the other hand there are cases where specific elements or minerals in pegmatites of this bulk composition seem to be derived from the surroundings, for instance Sc in thortveitite from hyperite; Mg and Ca respectively from dolomite and limestone; and Mn from Mn-ore, KILPADY and DAVE (1954). Possibly also the content of B, as fixed in tourmaline, can in some cases be correlated with original B-concentrations in marine shales, VON VOLBORTH (1955). In some pegmatites minor amounts of minerals such as sillimanite, andalusite, cordierite, and amphiboles are found to occur near the contacts with wall rocks, which carry the same, or related, phases, in which case assimilation seems most plausible; in other cases the indications for a possible derivation of material by this process are less direct.

An extreme case, in which most of the material in the pegmatite seems to stem directly from the wall rocks has recently been examined in great detail by REITAN (1958).[1] He has been able to establish that two pegmatite veins in hyperite in southern Norway are surrounded by well defined zones in which the components of the veins have been extracted from the hyperite. Thus the content, for instance, of plagioclase steadily decreases in the hyperite towards the pegmatite veins. It should be noted, however, that these veins differ markedly from the types of granitic pegmatites treated in the present paper. They lack microcline and specific mineralization, and the alteration of the wall rock is of a kind opposite to that found in connection with normal granitic pegmatites.

Wall rock alteration around granitic pegmatites deserves interest not only in order to discriminate between lateral secretion and other possible ways of formation. It also gives an indication of the nature of the components which left the pegmatite mass before, and during, consolidation. Reports on this subject have been compiled by FERSMAN (loc. cit., p. 289—309) and JAHNS (1955, p. 1067—1070). The following generalizations seem to be justified by that crop of observations.

Most pegmatites have produced no, or very insignificant, changes in their wall rocks. Those changes which have been observed comprise, apart from the introduction of minerals belonging to the pegmatite paragenesis, the addition mainly of potassium, silica, and water. This is evident from the formation of biotite from amphibole, muscovite from sillimanite and kyanite, tremolite

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[1] An exhaustive report has appeared in Norsk Geologisk Tidskr. 1958. during the printing of the present paper.

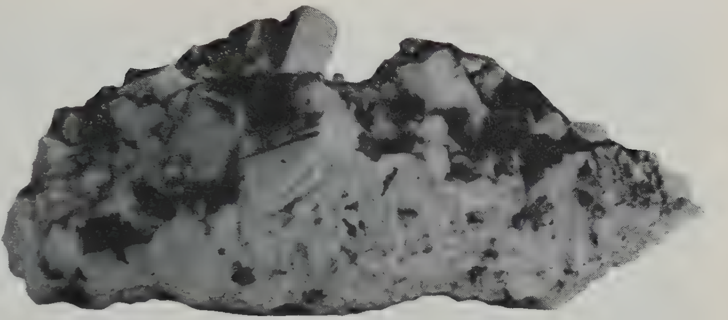

Fig. 29. Small crystal cavity from Baveno, Italy. Orthoclase crystals represent the pegmatoid zone, and are partially overgrown by albite and mica, (dark), which represent the core margin group. In the section seen in the front bottom, graphically intergrown quartz is barely visible. 1.3:1.

O. B. coll. & phot.

and diopside from Ca—Mg carbonates. To this can be added the formation of phlogopite, antophyllite, antigorite, and talc in dunitic rocks, cf. PAGLIANI *et al.* (1941).

A most important observation from a genetical point of view is that fluorite is not often met with in the alteration zones around granitic pegmatites. Not even in the most favourable situation, that is when surrounding rocks carry carbonates is fluorite an important mineral. This is true also of strongly mineralized pegmatite deposits. At Varuträsk, the surrounding amphibolitic rock contains many thin lenses of carbonates, well within the reach of feldspathic and siliceous offshoots of the pegmatite, but in spite of the extensive Li—Na—Cs mineralization in the deposit no fluorite has formed here or elsewhere in its surroundings. Fluorite is likewise absent, or unimportant, in the Black Hills Li-pegmatites, even in the surroundings of the Edison deposit, where quartz, carbonates, and sulphides have been introduced, PAGE *et al.* (1953).

Scapolite also is not a characteristic accessory of granite pegmatites or their alteration haloes, even if it is occasionally met with abundantly, VON ECKERMANN (1922), LAITAKARI (1916, 1921).

Cavities

Observations on cavities in pegmatites and closely related features in granites also may yield additional information, primarily on phase relations and on the original composition, for evidently some of these empty spaces once may have been filled by gases, liquids or soluble substances, which now have disappeared, but which eventually played an important rôle in the development of the pegmatite. From the review of pertinent literature given by JAHNS (1955, p. 1099—1101), one can see that the problem is fairly complex. Limiting this section to primary cavities only (for distinctive features cf. JAHNS 1955, p. 1100, 1101), it may be noted that a large group of these take the place of the quartz core or parts of it, both in space and in the paragenetical sequence. The relations in space are very clearly seen at Baveno, Italy, as already mentioned in the description of the zoning in those pegmatite lenses. The same is evident on Fig. 17, p. 1089 given by JAHNS (1955).

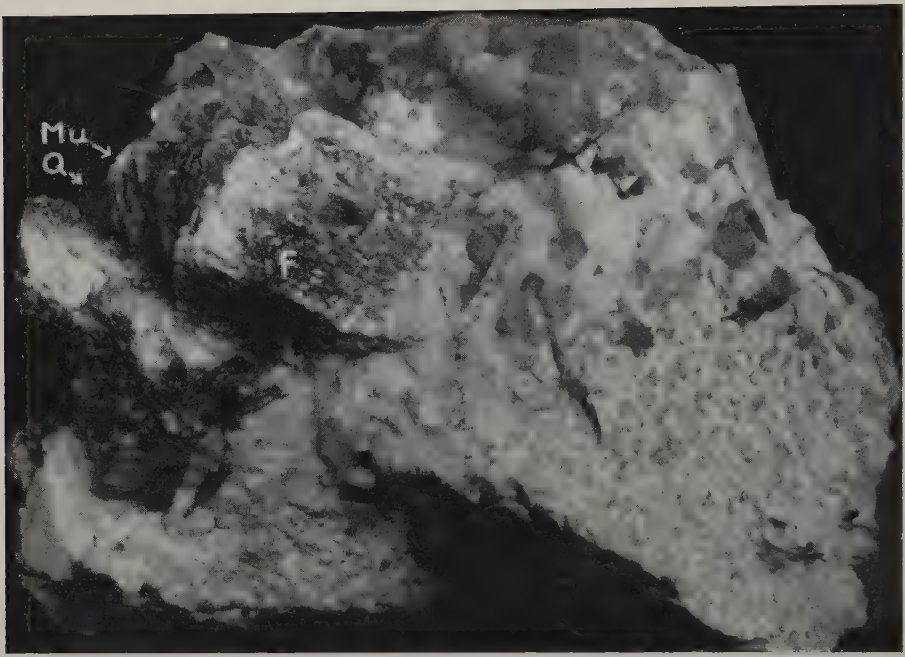

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Fig. 30. Pegmatite with crystal cavity (upper left corner). Graphic granite, (in lower right corner), with increasing grain size toward the cavity, from which is it separated by an intervening pegmatoid zone of K-feldspar, (light, with regular cleavage), albite (grey) and a little fluorite (dark grey). The core margin group is represented by crystals of K-feldspar (F), and muscovite (Mu), which project into the cavity and equivalent quartz-core (top). The surface of feldspar crystals in the cavity is heavily replaced by mica and albite, which represent the alkali-replacement group. (The mica is the dark coating, albite is small white crystals.) Q is a late quartz crystal in the cavity (»hydrothermal»). 1.1 : 1. Cornwall, England.

The equivalence in the paragenetic sequence has been noted in the field at Baveno, Fig. 29, in Cornwall, Fig. 30, and in some (very few) Swedish pegmatite deposits, and further on hand specimens from Adoun—Tchoulong and Alabaschka. It also emerges from many descriptions in literature. It is marked by a number of features; thus the walls are made up of K-feldspar crystals, which project into the voids and which correspond to the innermost part of the microcline zone in the normal basic zonal pattern. Often one can note an outer shell of graphic granite, which zone in some cases, as in the specimens for Fersman's work on the graphic structure (1928), even reaches into the open space.

Later mineralizations in these cavities comprise mineral associations of widely differing types. In some, no special minerals are found at all, in others, the K-feldspar crystals are overgrown and corroded by muscovite, gilbertite, platy albite, and quartz crystals and also by other typical representatives of later pegmatite mineralizations, such as coloured tourmalines and lepidolite. This clearly parallels the developments in zoned granitic pegmatites, and the boundary between the K-feldspar crystals and the open space evidently corresponds to the boundary between the microcline zone and the quartz core.

In other cavities topaz seems to be a characteristic mineral, and finally there are also examples with rather low-temperature mineral associations comprising carbonates and sulphides, even sphalerite and galena, GILLSON (1927), and zeolites. For further references cf. FERSMAN (1931, p. 283—288). This paragenesis marks an extension of mineralization beyond the pegmatitic stage, which deserves interest especially because it took place in a closed space, where introduction of material from external sources was in all probability excluded. The theoretical importance of this has repeatedly been stressed by NIGGLI.

Finally a note on observed trends in the occurrence of pegmatite cavities seems justified. It is remarkable that these cavities are generally very rare in Fennoscandia in spite of vast areas of granites and pegmatites. From personal mapping of some thousand square kilometers of uniform small- and even-grained granite in northernmost Sweden, the author cannot recollect one single find of such cavities, and this is fairly representative of most of Fennoscandia. Noteworthy exceptions to this are some areas of Rapakiwi granite in Finland, and some supposedly related rock massifs in Sweden. Apart from these minor exceptions conditions in this respect in Fennoscandia are thus in marked contrast with relations as found in a number of younger granites and related pegmatites of central Europe, e.g. at Striegau, Silesia, and at Baveno, Italy, cf. FERSMAN (1931).

Seeking for a correlation of this trend with any geological parameter besides that of absolute age it is found that in Fennoscandia granite areas generally are large and set in an environment of regional metamorphism, whereas the cavity-bearing Hercynian granites of central Europe are stocks of moderate size and surrounded by distinct aureoles of contact metamorphism. Thus there is evidently a correlation between the occurrence of cavities and that quality in connected granites, which WALTON (1955) termed metamorphic or thermal disharmony.

Relations with Metamorphism

The relationship between mineral associations in pegmatite deposits and metamorphism has been briefly commented on by FERSMAN (1931, p. 582, 583), and in recent times repeatedly emphasized by RAMBERG (1949, 1956).

The latter claims (1949) that »pegmatites and quartzo-feldspathic massifs usually possess mineral associations in harmony with the degree of metamorphism prevailing in the surrounding region». This thesis even forms the fundament of his hypothesis on the origin of these two groups of rocks.

Restricting the following discussion of RAMBERG's arguments to systems without pyroxene, we find that he (1949) uses two criteria to establish the harmony with the degree of metamorphism in surrounding regions, namely the occurrence of epidote and the spessartite content of garnets.

The case of epidote is best illustrated by rewriting his equation No. 2:

high temperature low temperature

$$\underset{\text{anorthite}}{2CaAl_2Si_2O_8} + {}^1/_2H_2O \rightleftarrows {}^1/_2\,\underset{\text{kyanite}}{Al_2SiO_5} + \underset{\text{epidote}}{Ca_2Al_3Si_3O_{12}(OH)} + \underset{\text{quartz}}{{}^1/_2SiO_2}; \qquad (1)$$

into

$$2CaAl_2Si_2O_8 + {}^1/_2H_2O \rightleftarrows {}^1/_2\,Al_2O_3 + Ca_2Al_3Si_3O_{12}(OH) + SiO_2; \qquad (2)$$

for it is in this connection unessential whether the alumina appears as such, or in the form of kyanite or as the difference between muscovite and orthoclase.

On the basis of equation (1) and regarding metamorphic rocks as open systems in respect to water, RAMBERG constructs a subsolidus diagram of the plagioclase—epidote (—alumina—quartz) equilibrium. This simply relates the stability of plagioclase with its anorthite-content, such that calcic plagioclase is in equilibrium with epidote etc. at higher PT (amphibolite facies) than sodic ones (epidote-amphibolite facies). So far this is a quite reasonable first approximation, even if no allowance is thereby made for the rôle of Fe and Ce, which both empirically and theoretically may be expected to stabilize epidote considerably. It is definitely wrong, however, to use the occurrence of epidote in combination with sodic plagioclase as a criterion of epidote-amphibolite facies conditions on the basis of this diagram, for it is only applicable if the epidote is actually formed from the plagioclase. If the epidote is of a different origin its transformation into plagioclase requires an adequate supply of alumina, in one form or other, as demonstrated by equation (2). If no alumina is available epidote may for all reasons exist in far higher PT regions, and its disappearance is governed by other equations. The stability field of epidote will, likewise, be extended if there exists an abnormal concentration of water in pegmatites. Of the four examples from literature of occurrences of epidote in pegmatite which are cited by RAMBERG, three cases characteristically refer to instances where the wall rock carries ample epidote. Further, RAMBERG's data are insufficient, for he makes no attempt to ascertain that alumina was available or the local activity of water not too high. In only one case is a source for alumina (muscovite) stated to be present, but no indications of that it was available during the crystallization of epidote are given. Finally, the fourth example given by RAMBERG refers to South African pegmatites, where, however, epidote is explicitly stated to belong to a late hydrothermal stage of mineral formation, GEVERS *et al.* (1937, p. 55). This is an important feature, which will be emphasized later in this section.

Regarding the spessartite content of garnets, RAMBERG likewise gives a subsolidus diagram implying that the Mn-content of garnets in equilibrium with biotite and potash-feldspar is a direct function of the degree of metamorphism. No evidence in support of this claim, neither a theoretical derivation of this function nor empirical data, is offered. Even if such a relation should exist in a broad sense the underlying assumption that variations in the Mn-activity in the total system should be without influence on the Mn-content in garnets seems highly improbable. RAMBERG makes no attempt to establish the extent of this influence, nor to estimate the total Mn-content of the rocks he deals with and its distribution between the various minerals which are capable of taking up Mn.

The best documented case from literature which Ramberg cites as evidence along this line for a harmony between the mineral associations in quartzo-feldspathic massifs and the degree of metamorphism in the surrounding region, is the Dartmoor granite, which is well known through the detailed investigations by Brammall *et al.* (1932, 1936). From these Ramberg quotes that the Mn-content of fourteen analyzed garnets from the massif ranges from 3.3 to 22 per cent MnO, corresponding to 8 and 51 per cent spessartite respectively. The only conclusion consistent with Ramberg's premises would be that conditions equivalent to the degree of metamorphism varied within the massif, the bulk chemistry of which is constant within moderate limits. Ramberg instead proposes that the presence of biotite in cases of garnets with more than 7.3 per cent MnO might be in doubt, and that the evidence places the granite in the amphibolite facies. The lower limit of the variation in biotite content of the Dartmoor granite is, however, by Brammall given as 2 per cent, so samples without biotite should be comparably rare, and definitely not among those which furnished Brammall's data (and Ramberg's) on the Mn-content of garnets.

The example of the Dartmoor granite further proves the incorrectness of Ramberg's approach, for according to the same descriptions, (Brammall *et al.*, loc. cit.) the granites are surrounded by zones of hornfelses, so any claim of harmony with a surrounding region in the amphibolite facies remains essentially without sense.

Leaving Ramberg's argumentation at this, the following observations may be added to the general subject.

It is well-known that many »quartzo-feldspathic massifs» are in disharmony with the metamorphic grade of the surrounding region. Most examples of this are granites which, like the Dartmoor granite, are surrounded by well defined zones of contact metamorphism. For further comment on this aspect, cf. Walton (1955).

Regarding granitic pegmatites relations are somewhat different, and there are cases where the mineral association in pegmatites is of a lower grade than in the surrounding rock. One example which in many respects is reminiscent of Ramberg's description of relations in the granulite facies area of Western Greenland is found in the area of charnockitic rocks of Varberg, Sweden, which has been described by Quensel (1951). Here, according to observations by the writer, two types of pegmatites are found. The one type is characterized by the same brownish-gray antiperthite as is the charnockite. Moreover hypersthene, hornblende, and biotite are also present in these pegmatites, which are in the form of somewhat irregular veins. However, in similar charnockite a few straight pegmatite dykes, with pink potash feldspar, grayish-white plagioclase, biotite, and quartz are also found. Cf. Ramberg (1949, p. 44)! Now, it is unlikely that two types of pegmatites would result from identical physicochemical conditions in similar rocks, furthermore the same pink and white type of pegmatite is also found throughout a vast surrounding non-granulitic gneiss area. From the first statement it is evident that the pink and white pegmatite must be in disharmony with at least one surrounding, and from the second observation it may be concluded that it is in disharmony with and of lower grade than the charnockite. Another example of the same general type is given below.

However, when speaking of PT-conditions in pegmatites or of harmony with some specified facies or grade of metamorphosis it is absolutely necessary to realize that within one individual pegmatite deposit, and often separated from each other by distances of a few meters or less, there may be found mineral associations which indicate widely different conditions of formation. To cite a striking example, garnet is formed in the earliest stages of development in the Varuträsk pegmatite and endogene montmorillonite and kaolinite in very late stages, QUENSEL (1956, p. 14 and 114). This is in no way unique, but has been reported many times from various localities. Because of this one must exercise extraordinary care and discrimination when discussing equilibra or natural associations of minerals in pegmatites. The existence of multistage mineralization in pegmatites and the fact that they represent more or less continuously decreasing PT conditions has been demonstrated by a great number of independent investigators. One of these is GEVERS, cf. GEVERS *et al.* (1937, p. 51—55), and it is in that same section that the occurrence of epidote in South African pegmatites is mentioned, which is cited by RAMBERG in support of his thesis.

The last observation to be offered refers to the fact that pegmatite deposits with nearly identical, highly special mineral associations may be found in regions with different degrees of metamorphism. In the Custer district of the Black Hills, for instance, a number of Li-pegmatites occur, whereas regional metamorphism is in part characterized by high-grade minerals like garnet and sillimanite, PAGE *et al.* (1953, p. 6 and 54). These metamorphic minerals are not encountered in the region around Varuträsk, which pegmatite deposit is very similar in mineralization, and where rocks of the surrounding region represent the same, or closely related, types of original sediments, but are of a different metamorphic grade.

After thus establishing that at present there exists no factual basis which permits any generalized statements on strict relations between surrounding metamorphism and mineralizations in quartzo-feldspathic rocks, and likewise, that proposed petrological short-cuts seem to be unreliable, the subject of this entire section may be summarized in the following way:

Granitic pegmatites are generally restricted to areas of some metamorphism. In this respect they resemble other deep-seated intrusive rocks and differ from effusive or hypabyssic ones.

Correspondence between PT conditions as indicated by mineralization in pegmatites and surrounding metamorphic mineral assemblages may occur in some fields and not in others. This resembles the regional zoning in pegmatite districts, cf. FERSMAN (1931), VARLAMOFF (1946, 1954), HEINRICH (1953), which is found in some regions, and which cannot be perceived in others. Cases, where, in all probability, lower PT conditions are indicated by pegmatites than by the surrounding rock seem to exist. Due to the sequential nature of mineralization in pegmatites it is to be expected that PT conditions as estimated by various means on pegmatite minerals, will, at least statistically, be somewhat lower than those prevailing at the time of emplacement. (It is, however, believed that this does not invalidate the examples given above to illustrate that pegmatites may indicate lower metamorphic grade than the surrounding rocks.)

Structural Relations with Wall Rock

Observations on structural relations between pegmatites and wall rocks have for long been important arguments in the discussion on the genetical problems, cf. JAHNS (1955, p. 1038 and 1064—66). There is by now well documented evidence for emplacement by forceful injection, brecciation, and dilation as well as by porphyroblastesis and metasomatism without much dilation in the surrounding rock, (even if in selected cases employed criteria cannot be accepted without reservations). This being so, further descriptions here seem unnecessary. Instead reference is made to the review by JAHNS, cited above, and the sources he quotes. On the other hand there exist marked divergencies in the interpretation of these observations, but discussion of this is deferred to the general section on interpretation.

Discussion

Outline of Problems

Knowledge of the sequence and characters of mineralization in granitic pegmatites is perhaps the best single clue for analyzing the processes within the pegmatite bodies during their formation. Even so, this remains just one part of the complex geologic problem posed by these rock bodies. Some auxiliary aspects have also been briefly presented in previous sections, but it is quite outside the scope of this paper to give an exposition of the entire geological picture of the subject. Nevertheless such a background is necessary for an adequate treatment of the problems of mineralization, for this alone could give information as to which geological and physico-chemical conditions can reasonably be assumed to have prevailed during the formation of the pegmatites.

Existing observations on granitic pegmatites have been coordinated into a few general theories on their genesis. Of these the magmatic theory, which implies that granitic pegmatites were derived from, or emplaced as, magmas, wholly or partially liquid, represents the most widely accepted approach toward the problems of mineralized granitic pegmatites, cf. JAHNS (1955, p. 1058—1064 and 1070—1098). A small group of investigators, however, has also tried to explain the genesis of pegmatites along other lines, preferentially by seeking to establish analogies with processes in metamorphism and with metasomatism. These differences in views cannot all be bridged simply by stating that »there are pegmatites and pegmatites», for it is evident that some of these non-magmatic explanations are intended to be of rather general applicability, e.g. RAMBERG (1949, 1956).

The very existence of two rivalling main theories bespeaks the fact that both are not entirely satisfactory. The dominant rôle of the magmatic one, which has been statistically demonstrated by JAHNS, loc. cit., may, if sceptically viewed, be ascribed to its traditional nature, whereas the very minor rôle of the metamorphistic theories can be considered as due to their relative novelty. It can hardly be denied, however, that a wider acceptance among magmatists of these theories has also been hindered by certain shortcomings in some of their presentations. Here belongs the fact that in places little attention is given to such features which are generally taken to indicate a magmatic origin of pegmatites, along with insufficient evidence in support of metamorphistic views, cf. p. 61—63, and some remarkable slips of logic (e. g. "Lenticular conformable pegmatites so commonly encountered in gneissic schists [for example, the Black Hills pegmatites (FISHER 1942, 1945)] appear to have pushed the country rock in front of their expanding boundaries, thus proving that the mechanical pressure in the pegmatite bodies has been greater than in the surrounding gneisses. Consequently, the introduced material has, during the formation of the pegmatite, moved from low toward high mechanical pressure". RAMBERG (1949, p. 21, 22.) These shortcomings should, however, not be allowed to obscure the importance of these papers in pointing out a number of severe difficulties inherent in any simple magmatic theory of pegmatite genesis. A short review of some of the difficulties which thus afflict the two general theories may be of aid in the final choice of a starting point for the following interpretation.

Problems of Mineral Sequences

One type of most aggravating difficulties is posed by the character and sequence of mineralization in zoned granitic pegmatites, for this sequence is not to be explained on the basis of normal fractional crystallization in a restricted system. Likewise the constancy of this sequence, together with much evidence from detailed mapping, seems to preclude in most cases the possibility of relating late mineralizations with late introductions of independent solutions into preexisting pegmatites. The extreme scarcity of independent mineral deposits with compositions corresponding to such late mineralizing fluids also speaks against this latter possibility as has been pointed out by VLASOV (1955 p. 56).

This difficulty has been recognized and admitted also by some adherents to the magmatic theory, cf. JAHNS (1955, p. 1094). In order to overcome the problem, for instance as posed by the common quartz core of granitic pegmatites, JAHNS (loc. cit.) proposed the action of resurgent boiling, and the same process is by him believed to explain the important rôle of replacements in granitic pegmatites (loc. cit., p. 1097). Critically viewed this is essentially an escape into the unknown, for at present there exists no conclusive information on whether resurgent boiling occurs at all in systems of pegmatitic composition, nor is it known whether it would effect the changes it is called upon to explain. Considerations of available space in pegmatites and also of thermodynamics seem to restrict the potential rôle of a vapour phase within pegmatites in these specific respects, as will be detailed later.

Structural Problems

Other difficulties pointed out by Ramberg (loc. cit.) relate to clear evidence of metasomatic emplacement and to the structural behaviour of some pegmatites, which seems to demand rather remarkable mechanical properties of the assumed pegmatite magma. Relations of one and the same pegmatite body thus often appear to indicate that the magma must have been fluid enough to permit feeding through channels which are extremely narrow, sometimes not even recognizable by the unaided eye, yet viscous enough to support huge fragments of the wall rock.

Correlation with Intrusives

Very great difficulties are also encountered by proponents of a non-magmatic theory of granitic pegmatites. Above all there are the numerous cases giving clear geological, mineralogical, and chemical evidence of a close connection between pegmatites and thermally disharmonious intrusive rocks. Many descriptions of such instances have been listed by Jahns, as indicated earlier in this section, and there seems to be no justification for recapitulation here. To the writer field observations in Cornwall and at Baveno have been most impressive in this respect. Relations as illustrated in Figs. 1, 2, 6, 7, 8, which appear to indicate repeated introduction, consolidation, and fracturing and renewed introduction in the fractures so formed, of various granitic, aplitic, and zoned pegmatitic bodies within a limited span of geological time, during which, by all evidence, metamorphic conditions remained approximately constant, should also be cited in this connection.

The fact that there are fields with granitic pegmatites but without known intrusive bodies, with which they may be correlated, does not detract from this close connection in other cases. In combination the evidence can be explained either by the assumption that there are pegmatites which are connected with bodies of intrusive rocks and others, which are not, or that there are cases, where the intrusive is not exposed within the area of investigation.

Regular Trends in the Properties of Minerals

A similar situation seems to exist in regard to regular trends in chemical and physical variations in mineral components within individual pegmatite deposits. These have been known to exist for a long time, cf. Fersman (1931), and a most recent contribution of this kind, along with a magmatic interpretation, has been given by Staatz *et al.* (1955). Detailed correlations of refractive indices of biotite and muscovite with the An-content of plagioclase have been made for individual deposits by SHIBATA, loc. cit., whereas in other fields no such correlation has been found, e.g. RAMBERG (1956). (However, this aspect may be less critical, for such effects could also result from fractionation in non-magmatic systems.)

Variations in Temperature and Occurrence of Rare Minerals

Other difficulties which are encountered by a metamorphistic approach arise from the large range in temperatures manifested in some pegmatite deposits, and from the occurrence of rare constituents. The first feature has been briefly discussed in considering relations with regional metamorphism. Regarding the second point there has been much divergence in thought. In the writer's opinion no significant conclusion can be drawn directly from the fact that rare elements and minerals sometimes are found concentrated in pegmatite deposits. In the magmatic theory they are separated from common minerals by fractional crystallization and in the metamorphic theories fractional mobilisation is taken as the operating mechanism. In both theories the crucial point is the distribution between ordered and disordered phases and the bulk chemistry and mineralogy of the systems involved are much the same. It may thus be presumed, as a first approximation, that similar physicochemical properties will govern the mechanism and distribution in either process.

Nor can too much importance be attached to the fact that minor minerals, as for instance minerals of the rare earths, Ta, and Nb sometimes are and sometimes are not observed, for according to the writer's experience, these minerals are often highly localized in a restricted part of the deposit and the paragenetical group to which they belong. Here they may be found in great amount and of large size, whereas they are not to be observed in identical paragenetic positions in other parts of the same pegmatite deposit. Due to this it remains largely a matter of chance whether these minor minerals are encountered or not.

A different situation is however created by some rare constituents which form major components of individual pegmatite deposits or paragenetical groups within these. The best example is furnished by the Li-minerals, for much detailed information on their occurrence exists, due to their general economic and mineralogical interest. It is thus well documented that Li-bearing pegmatite deposits are usually found together with a very much greater number of similar pegmatites where no, or only very faint, traces of Li-mineralization can be found in spite of intensive search. These marked mineralogical and chemical variations between adjacent pegmatite bodies, where the chemical composition of the wall rock, as well as its metamorphic grade show no essential differences, seem difficult to account for on the basis of metamorphism. The magmatic theory accounts for such differences in terms of magmatic and post-magmatic differentiation. Even if the mechanism of such processes is not always understood, there is enough clear geologic evidence that such complexity does arise in connection with magmatism. For example in granite quarries in Cornwall the granite is transected by numerous small quartz-tourmaline veins, some of which do carry minor sulphides and traces of wolframite, while others do not, and both the granite and the veins are cut by straight dykes of quartz-porphyry. Without doubt similar complex relations could be cited from descriptions of volcanic necks, if the Cornish granite is not accepted as a representative of magmatism.

A rather special case worthy of consideration in this connection is the earlier mentioned occurrence of beryl in the core margin association found surrounding a mass of hyperite enclosed in the quartz core of the Högsbo pegmatite. If it is supposed that the minerals crystallized from a magma or disordered phase which filled the space now occupied by the pegmatite, this occurrence simply indicates that the hyperite mass acted as a substratum for the crystals. If, on the other hand, it is assumed that the minerals grew as solids fed by diffusion from the walls it would imply that the amount of beryllium now present as beryl should originally have been contained in the limited mass of hyperite, or that it migrated to its present position from the outer walls and across the space of the present quartz core which, however, seems most unlikely for obvious geochemical and thermodynamic reasons.

Choice of a Starting-point

It thus appears to the writer that non-magmatic theories for the genesis of granitic pegmatites also encounter a number of difficulties. Further, he is not aware of any moderately detailed attempt to account for, in non-magmatic terms, the specific nature and sequence of mineralization of complex granitic pegmatite deposits, which thereby masters the serious shortcomings of magmatic theories in these respects. Apparently JAHNS, in his extensive search of the literature on pegmatites, likewise did not come across any such publication. Among the rivalling theories on pegmatite genesis, in their present state of elaboration, the magmatic theory therefore is the one embracing the greatest crop of observations. It may therefore also seem premature entirely to discard the magmatic theory and favour some divergent, more or less sketchily conceived idea on pegmatite genesis. Thus an attempt first to resolve some of the problems of the magmatic approach should be appropiate. All this must, however, not be taken as a confirmation of the magmatic theory of pegmatite genesis, so far it is only intended as a justification for a choice of that particular conceptual model as a starting point. On the contrary, an amplification of the difficulties inherent in any simple magmatic theory is a prerequisite to their overcoming.

Analysis of the Problems of Fractionation

The marked mineralogical fractionation, which is found to follow rather regular trends in a great number of granitic pegmatites, constitutes one of the major problems of pegmatite genesis. In passing it may be remarked that this is true not only of the magmatic theory but also of the non-magmatic ones. At present neither of them furnishes an explanation for it, apart from very general hints on the possible effects of resurgent boiling and differences in the rate of diffusion, activation energy, ionic radii, electronegativity of various ions, etc.

The most acute problems in recent discussion of pegmatitic fractionation are those of the late quartz core and marked, post-consolidation replacements. In the writer's opinion these partial problems cannot be solved without regard to the reactions in the rest of the system. If, for example, when considering the common quartz core, it is assumed that the crystallization of silica is delayed by the action of water and excess alkali, this without doubt reveals one of the import aspects of the genesis of this crucial pegmatite unit. There is much experimental evidence for this mechanism, cf. MOREY and FENNER (1917), MOREY and FLEISCHER (1940), MOREY (1942), MOREY and HESSELGESSER (1952), TUTTLE and FRIEDMAN (1948), FRIEDMAN (1950), and its possible applicability to petrogenetic problems has been suggested repeatedly, cf. GOLDSCHMIDT (1920), JAHNS (1955), ROY and TUTTLE (1956), ESKOLA (1956). There are, furthermore, processes like resurgent boiling and "osmotic distillation", cf. JAHNS (1955, p. 1082, 1094), TURNER and VERHOOGEN (1951), which provide means for a final escape of the solvents. Such processes could be accepted as an almost satisfactory answer to the question why alkali silicates are never found in pegmatites (not even in primary cavities, but eventually in the solutions of liquid inclusions).

However, the same experimental evidence clearly indicates that silica in its maximum concentration represents only about 50 per cent by weight of these solutions in the pertinent range of temperature (400°—250° C). Regarding the lower density of any vapour phase and the high probability that some silica would leave the pegmatite body together with the alkalis and water (cf. also the section on exchanges with the wall rock) it is a very conservative estimate to conclude that the material of the quartz core under these conditions should prior to its consolidation occupy a space equal to at least twice its final volume.

Now, cavities are rare in pegmatites, and even where they are most abundant they hardly exceed 1 per cent of the volume of the entire pegmatite body, BASTIN (1911). Evidence of minor late deformations is, likewise, often found, but nowhere have indications of large-scale slumping in earlier consolidated zones been observed, which would account for the filling of the space once occupied by the solvents of the quartz core. Thus field relations seem effectively to bar the possibility of the action of water and excess alkalis combined with resurgent boiling being sufficient to explain the existence of large quartz cores.

Reasoning along similar lines suggests that there was no space for large-scale transfer of matter in a vapour phase in most pegmatites, and thus resurgent boiling seems inadequate to explain major replacements. It must further be recalled that even if one homogeneous phase is split into two or more, be it by liquid immiscibility, ordinary boiling or resurgent boiling, the chemical potential of every one constituent will be the same in all phases thus produced. This means, that the final products will be the same whether the solid phases are in contact with the homogeneous melt, or with either one of an immiscible pair, or with the vapour phase, and that any reaction products formed on recombining the partial phases are the same as those which would have been formed if the homogeneous phase had reached the same state without splitting.

The splitting by itself thus cannot cause any changes in the relative stability of minerals as is required for replacements. These are naturally caused by changes in the chemical potentials due to changes in temperature, pressure, and concentrations of participating constituents. If such changes occur a mobile vapour phase is only one of the possible means of realization of the reactions. (The same is true of the case when there exist physico-chemical gradients within the pegmatite body, then vapour transfer of matter could be promoted if space relations permit). An illustration of the similarity in end products whether a gas phase intervened or not is possibly furnished by primary cavities in granites and pegmatites, for here there is some reason to assume that they were once filled by a gas phase. As mentioned earlier the same minerals may occur in these cavities as in the later stages of ordinary pegmatites, especially minerals of the core margin groups and alkali replacements.

These thermodynamic considerations are clearly valid only under the assumption of a closed system. If a part of the system (a more mobile phase) is allowed to escape it would most probably change the process. It may be presumed that the main effect would be an elimination of the later stages of pegmatite development, but replacement reactions can hardly be expected to occur. This escape could eventually explain zoning in pegmatite districts. That topic is, however, outside the subject of this section, which is to discuss the problems of fractionation within pegmatite bodies. So far it has been shown that suggested explanations of partial problems are inadequate, and it is therefore advocated that for further advancement it is necessary to take, if possible, the entire development of pegmatite systems into consideration.

Significance of the Paragenetical Groups and Their Sequence

It will now be attempted to characterize the development of pegmatite systems on the basis of the division into paragenetical groups and their normal sequence.

In simple granitic pegmatites the following sequence is found: —

1 Granitoid border
2 Zone of graphic granite
3 Pegmatoid zone
4 Quartz core

Within this sequence we can distinguish both gradual and more abrupt changes. Among the gradual ones there may be noted increasing grain size and orientation of individual feldspar crystals inward, and decreasing content of plagioclase and biotite in the same direction. The more sudden changes define the limits of the separate groups, thus here are found the onset and ending of graphic granite crystallization, and the ending of crystallization of the pegmatoid zone (mostly of microcline) at the margin of the quartz core.

The increase in grain size and feldspar orientation evidently signifies gradual changes in the conditions of crystallization. The decrease in the content of plagioclase and biotite denotes a fairly strong fractionation, for often it leads to an almost monomineralic microcline zone in the inner part of the pegmatoid zone. Superficially this seems to be in accord with the order of crystallization in igneous rocks, but actually it differs from what may be expected to result from crystallization of a melt. Here plagioclase may well start to crystallize before microcline but finally a partial eutecticum should form, but not a monomineralic microcline zone. This unit therefore also constitutes one part of the general problem of fractionation in granitic pegmatites.

Much more market deviations from the ordinary course of crystallization are denoted by the more abrupt changes. The onset of the graphic granite crystallization may, however, be an exception. It is difficult to observe, and possibly, on microscopic investigation, is rather gradual in some instances. It can furthermore be taken to signify only a special texture of crystallization. This is a much discussed topic, and it will be further considered later. However, the ending of graphic granite crystallization and the onset of the quartz core are often most marked and sharp changes in the pegmatite system, as was earlier described and illustrated. The interval between these two events ideally marks a break in the crystallization of quartz, which can hardly be explained on the assumption of strictly magmatic conditions. It is believed to be of highest significance in any attempt to analyze the crystallization of pegmatites.

More complex granitic pegmatites are according to the present approach distinguished by the following mineralizations, which intervene between the pegmatoid zone and the core:

1 Appearance of muscovite
2 Core margin group
3 Alkali-replacement group
4 Core margin mica group

Of these the appearance of muscovite signifies primarily an increased activity of water, whether it forms directly or by a partial hydrolysis of microcline.

The core margin group signifies the cessation of crystallization of microcline and the continued and favoured crystallization of typical minerals of this group. Further indications on the changes in the pegmatite system at this stage may be gained from an inspection of the mineral members of this group. They can for convenience be subdivided into a number of groups according to their nature:

A Oxidic minerals, e.g. columbite, samarskite, cassiterite.
B Phosphates and fluorides, e.g. monazite, fluorite, apatite, Li—Na—Mn—Fe phosphates, amblygonite.
C Alumosilicates with small and highly charged cations, e.g. beryl, tourmaline.
D Alumosilicates with small cations of unit charge, e.g. albite, spodumene.

This grouping also corresponds approximately to their relative order of crystallization within the paragenetical group.

The alkali-replacement group signifies the instability of potash-feldspar in relation to other alkali-alumosilicates such as albite, spodumene, and petalite. The instability of potash-feldspar is indicated by the preferential replacement of this mineral, whereas most other phases, such as the minerals of the core margin group, may suffer only minor reaction changes or continue to form. It may be assumed with GEVERS (1937) that the replacement involved only an exchange of alkali ions, for it is difficult to imagine any chemical potential which could promote a reaction in which first the alumosilicate complex of potash feldspar is carried away, and then the same complex is again introduced to form albite. Such an alkali exchange also minimises the requirements for chemical transport and space of reaction.

The core margin mica group signifies a situation where the equilibrium between potash-feldspar and mica was displaced entirely towards the mica side. In other respects chemical conditions must resemble those governing the formation of the core margin group because of the great similarities in mineralogy. Conditions of crystallization differed as evidenced by the small grain size in the core margin mica group.

An additional step in this direction of development is indicated by the late alterations found in many pegmatite deposits. Here sericite and clay minerals often are dominant phases, whereas typical pegmatite minerals are absent. This paragenetical group indicates almost complete hydrolysis of the primary alumosilicate minerals.

Interpretation

Temperature of Pegmatite Systems

From contact relations of granitic pegmatites it is evident that most of them, even during emplacement, did not differ much in temperature from their immediate surroundings, irrespective of whether these are made up of metamorphic rocks or granitic "mother rock". (This should not be confused with the claims of a general harmony of granitic pegmatites with surrounding regional metamorphism as discussed earlier.) Generally no special evidence of thermal effects can be noted in the wall rocks, and the pegmatites themselves at most show some reduction of grain size near the margins, but even this must not necessarily be interpreted as a direct effect of chilling, as detailed later on.

From this it may be concluded that due to the moderate difference in temperature, cooling should have been relatively slow. Further, if the existence of a pegmatite magma is assumed, there follows from its co-existence with solid rocks of similar compositions, that the temperature must have been at the lower limit of the magmatic field, and that fluxing agents may have been as important as heat in keeping the system disordered. These simple deductions from plain field observations in many ways suffice for a qualitative understanding of temperature relations in pegmatite systems.

In recent times quantitative data on pegmatite temperatures have also begun to accumulate, much of which corroborate the qualitative deductions given above. A few of these temperature determinations, incidentally also furnish excellent examples of highly quantitative data (to within one degree C°!) with total lack of or only vague and tentative suggestions as to the most elementary qualitative specifications on their actual physical, chemical, geological or paragenetical significance.

The field of geologic thermometry has recently been surveyed by INGERSON (1955), so no attempt will be made to review earlier literature. Only summaries of some results, with comments, will therefore be given here. Each class of geologic thermometers will be considered separately.

Estimates

A. Changes in Crystallization

Inversion of quartz. This is one of the earliest thermometers used in the investigation of pegmatites and in many respects it has remained one of the most significant. Its main drawback is due to observational difficulties .The effect of pressure is well-known, and the paragenetical significance has been well ascertained by WRIGHT and LARSEN (1909), BASTIN (1911) and FERSMAN (1928) It thus appears that most of the graphic granite zone and preceeding formations crystallized well above the inversion temperature (about 600° C, if pressure is allowed for), that some graphic granite formed around this temperature, and that some extreme samples, with amazonite, from the Ilmen mountains (FERSMAN) crystallized entirely below the inversion point. Later pegmatite quartz, according to these investigations, seems to be all original α-quartz. More recent observations, which seem to limit the general application of this thermometer, such as on the development of secondary Dauphinétwinning also in α-quartz on quenching, or on the development of highly regular twins by localized pressure, and on the possibility to bring down oscillatorplates from 1 000° C without subsequent appearance of "etch cracks", FRONDEL (1945), hardly seem to have any direct bearing on quartz of pegmatitic provenance.

Spodumene. The natural modification of spodumene indicates that this mineral always formed below 500° C (or a slightly higher temperature), according to ROY, ROY and OSBORNE (1950). This gives a maximum temperature for the core margin and the alkali-replacement groups in Li-pegmatites.

Bismuth. Radial cracks, usually in quartz, around bismuth grains indicate that the latter were enclosed when still in the liquid state, for the cracks most probably are due to the expanding of the metal on solidification, RAMDOHR (1931). Bismuth generally is a paragenetically late mineral in pegmatites and tentatively the observations cited give an approximate temperature of the solidification of core quartz, 270° C.

B. Stability Relations

Stability relations of individual minerals seem to be difficult to evaluate properly, for chemical environment and available time may be very important factors, which are not easily approximated in synthesis. Nevertheless, diagrams like that illustrating the stability field of muscovite, as given by INGERSON loc. cit.

after Yoder and Eugster, are highly suggestive of temperatures prevailing in muscovite forming pegmatite systems. Cf. also Morey and Ingerson (1937).

C. Liquid Inclusions

Investigations of liquid inclusions have yielded quite a number of temperatures from pegmatite minerals. With a few exceptions these determinations have been made without sufficient regard to such important items as the primary or secondary nature of the inclusions, the salinity of the liquid, and, above all, the paragenetical provenance of the specimens under investigation (this includes neglect of the fact that a zonal unit is not neccessarily genetically homogeneous). These temperatures, therefore, are often of restricted value. At best it may be stated that typical pegmatite minerals, such as beryl, probably formed in a temperature-range from a little above 200° C, Weis (1953), to the upper limit of the applicability of the method, about 600° C, Cameron *et al.* (loc. cit.), where results become indeterminate. This presumably represents a range from the pegmatoid zone or the core margin to the last clear crystals in vugs.

D. Solid Inclusions

High-temperature decrepitations studied by Smith (1952, 1957) are claimed to originate from differences in thermal dilatation between host mineral and solid inclusions and are taken to indicate temperature of formation. Feldspar, probably from the pegmatoid zone of simple pegmatites (?), yielded 612° ± 20° C (K-fspr) and 608° ± 20° C (plag.). Fundamental assumptions seem to need verification, but results are in accordance with temperatures from the quartz-inversion thermometer. It is interesting to note that temperatures from the surrounding metamorphic rocks are reported to be a little higher.

E. Systems with Solid Solution

Systems with solid solutions seem to provide a increasing number of geologic thermometers. Two such thermometers, namely the FeS—ZnS system, Kullerud (1953), and the system albite-paragonite/muscovite, Grootemaat and Holland (1955), Eugster (1956), have been calibrated against normal thermometric scales by synthesis. The feldspar thermometer, Barth (1956), has also been calibrated more carefully than by the usual rough estimates of the temperature of formation for various rocks. The latter two thermometers have been used for temperature estimates of granitic pegmatites, and the first one is at least of potential interest.

Before accepting the validity of such thermometers one must ascertain that A) the phases considered crystallized in true equilibrium; B) pressure effects have been corrected for; and C) no noteworthy post-crystallization segregation has taken place.

Regarding the feldspar thermometer it is found that in many pegmatite bodies there occurs a fractionation leading to the formation of early (marginal) oligoclase, intermediate microcline, and sometimes also late, often cleavelanditic, albite. This can indicate non-equilibrium conditions, which might seriously affect the validity of feldspar thermometry. The rôle of pressure effects is difficult to ascertain, it is, however, striking that the upper part of the 1956 scale of values for the feldspar crystallization temperatures (BARTH, loc. cit.) is constructed from effusive rocks, a medium temperature derives from a metamorphic rock, and the lower part from deep-seated rocks. This might suggest control by a pressure effect but most probably it is largely a consequence of post-consolidation segregation. This process definitely is the greatest source of error in feldspar thermometry.

The exact nature and extent of this segregation is difficult to assess. It will obviously be favoured by slowness in cooling and in expulsion of hyperfusibles, i.e. in deep-seated intrusive rocks. True, if most favourable conditions are assumed to prevail during cooling, one can argue that most of the albite in spite of segregation will stay in the host crystals as perthitic intergrowths, and thus report in analysis as if no unmixing had taken place. This, however, hardly can apply if the rocks were subjected to simultaneous or later deformation, which is known greatly to enhance the mobility of mineral components. Feldspar thermometry can perhaps be uphold by correcting for deformation by measurements of textural orientation, but as it now stands it seems to loose most of its significance in deformed rocks. It may, in passing, thus be concluded, that low feldspar "temperatures" from pre-Cambrian granites and gneisses of Southern Norway, as discussed by BARTH most probably should be related to the pre- or syn-kinematic nature of the rocks, and are more plausibly explained by small scale — small range material transfer between adjacent feldspar crystals than by large scale — long range metasomatism.

After this general discussion of feldspar thermometry its application to pegmatites may now be considered. Here traces of deformation generally are absent or unimportant, so the main source of error probably is eliminated. Due to the poor paragenetical characterization of the samples tested by BARTH (loc. cit.) their significance can only be guessed. Let it be presumed, however, that they are from pegmatite bodies in which deviation from equilibrium conditions was not too great, and that the samples represent the pegmatoid zone. In that case the temperatures given by BARTH for larger pegmatites, i.e. about 600° C, correspond fairly well with temperatures as estimated by the quartz inversion thermometer and by solid inclusions.

No detailed account of temperature research with the muscovite—paragonite—albite thermometer has yet been presented, but from abstracts it appears that physiocochemical and paragenetical factors have received careful attention. Preliminary results indicate that in one individual pegmatite body muscovites register temperatures from 500° C to 350° C, in excellent agreement with the paragenetically determined sequence.

Results

Available temperature estimates thus indicate that granitic pegmatites were emplaced at well above 600° C (graphic granite), that feldspar and the earliest beryl crystallized at about 600° C (pegmatoid zone), that muscovite started to form at about 500° C (core margin?), that spodumene formed below about 500° C (alkali replacement and core margin), that beryl and muscovite continued to form until about 300° C (the higher range about 500° C probably representing core margin and equivalent assemblages and the lower range about 300° C later groups including cavity fillings); and finally that quartz (core) was brittle at about 270° C.

Pressure

No comparable measurements of the confining pressure seem to exist, but this parameter usually is deduced from geological estimates of depth of burial at the time of emplacement. Most such estimates indicate a depth of some kilometers, but clearly pegmatitic characters are found in some mineral deposits of a much more shallow origin, e.g. "Palisadenfeldspäte" in German tin deposits, which evidently formed only 600 m below the surface. Intensive alteration into topaz in that case indicates the active rôle of volatile agents, HEDRICH (1958). Actually variations in the nature and amount of volatiles seem to be the main consequence of differences in depth, for otherwise mineral composition and textures remain almost the same within granitic pegmatites. This aspect, however, will be considered in the following section.

Content and Nature of Fluxes

Besides estimates of prevailing temperatures and pressures knowledge of the composition of pegmatite systems is a prerequisite for a genetical interpretation. It is easy to state that the original system was made up of those components which now constitute the pegmatite body and those which left it before and during consolidation. Likewise it is quite reasonable to assume that the latter group comprises those evasive substances, very often and very loosely referred to as pneumatolytes, volatiles, or fluxes.

As indicated in the descriptive section the first place to look for these substances is in the enclosing rocks. Here are found K (less Na), SiO_2, and H_2O as the main introduced components, in some cases also tourmaline and phosphate minerals can be found. Contrary to expectation fluorides and chlorides are not fixed in the wall rocks, even under extremely favourable conditions. As many pegmatites likewise are poor in these substances, which also is valid for the Varuträsk pegmatite with its richness in rare alkalies, we must conclude that fluorides are not necessary components in pegmatite systems. This also seems to rule out the hypothesis on the genesis of granitic pegmatites involving distillation of fluorides which has been proposed by VLASOV, loc. cit.

Carbon dioxide on the other hand cannot be ruled out in a similar way. Due to its generally feebly aggressive nature it may escape fixation in pegmatite and wall rocks alike. On the other hand it is the most common volatile compound next to water, and is almost always present in liquid inclusions and other samples of "magmatic" gases. It is therefore a sound assumption that carbon dioxide is an important constituent of pegmatite systems.

Regarding the connection between confining pressure and importance and nature of fluxes let it be assumed that higher grade in regional metamorphism and larger areal proportions of granite indicate greater geological depth, whereas higher content of cavities, muscovite, fluorite, and topaz denotes increased activity of volatiles. It then seems quite apparent that deeply eroded areas are characterized by granitic pegmatites poor in volatiles, whereas intermediate areas are characterized by muscovite pegmatites and areas which only are laid bare to shallow depths are characterized by the formation of greisen with fluorite and topaz. These differences, however, are of a secondary order only, and already the pegmatites of the deep and intermediate zones exhibit the characteristic textures, fractionations, and replacements of the pegmatite group. Thus it should be permissible to reduce the complexity of the problem by first considering pegmatite systems which are made up of their mineral components and limited amounts of fluxes such as alkali-silicates, and the simple volatiles water and carbon dioxide.

It may be interesting to conclude this section by cross checking at this stage the consistency of inherent assumptions. It is thereby found that the aspects of temperatures and compositions of pegmatite systems as here compiled in combination with recent melting experiments, as reported on by JAHNS (1957) and TUTTLE *et al.* (1957), are perfectly compatible with the assumption that granitic pegmatites may have been emplaced as magmas.

Aspects of Crystallization

Crystallization is a critical item in pegmatite discussions and some of the most characteristic features of these mineral deposits, such as marked fractionations, the extraordinarily large size of crystals, and many textural combinations of mineral components belong here.

It may be appropriate to repeat here some of the most significant observations relating to pegmatites of the basic zonal pattern.

1) Crystallization proceeded from the walls inward.

2) Grain size increases from the granitoid wall zone to the inner part of the pegmatoid zone (microcline zone) and the core margin.

3) Fractionation among major constituents tends to split the multimineral eutectoid crystallization of the granitoid zone into zones with a decreasing number of major mineral components, eventually giving rise to a monomineralic microcline zone and a quartz core in the central parts of the pegmatite body.

4) Splitting is in accordance with what may be expected from melting points and concentrations, leading to early crystallization of biotite and oligoclase, intermediate crystallization of microcline and late crystallization of albite, spodumene, beryl, and other core margin minerals.

5) Many minor oscillations or deviations from this rule occur.

6) Quartz behaves systematically abnormally.

Apart from the last point, which requires special consideration, all this may be fundamentally explained by assuming that crystallization within pegmatite systems proceeds as an increasingly reversible process, which is caused by heat and solvent loss to the surroundings, and which takes place at very low "magmatic" temperatures.

That the crystallization is caused by heat and solvent loss to the surroundings is almost trivial. It is difficult to think of any other cause for crystallization and likewise there seems to be no other place in which to dispose of excessive heat and solvents. Direct support is supplied by the falling temperatures in the paragenetical sequence. Likewise this loss to the surroundings gives a ready and almost self-evident explanation for why crystallization starts at the walls, and also provides a possible mechanism for the attainment of reversibility.

Granitic pegmatites, as indicated earlier, generally show little thermal contrast relative to their immediate surroundings, either they are found in metamorphic rocks, or in areas of low metamorphism where they are held inside thermally disharmonious granite bodies. Temperature gradients will therefore be low at the outset, and the heat released from the pegmatite will smooth them out still further. Likewise the earliest crystallization at and in the walls will prevent further escape of solvents. Hereby crystallization ideally may become reversible and therefore very sensitive to small changes, for instance in confining pressure. This, in turn may explain many of the minor irregularities in the course of crystallization as observed in pegmatites.

The fact that crystallization in pegmatites takes place at very low "magmatic" temperatures and below, has been sufficiently demonstrated in the section on temperatures. This fact implies that pegmatite systems, in comparison with other silicate systems of similar concentrations, for instance lavas, are very low in thermal energy. Their content of fluxes does enhance mobility, and thereby also crystal growth, but it does not change the energy balance. As is well known, cf. NIGGLI (1948, p. 378—380), energy is required for the formation of crystal germs. Now, if pegmatite systems are low in energy it may be expected that germination likewise is low. If this is correct, it may, in combination with the two other aspects already discussed, explain the huge size of individual crystals as well as the marked fractionation and the frequent occurrence of combination textures in pegmatites.

The size of crystals may be expressed as the mass of crystallized substance divided by the number of growth centres. The increased grain size in the interior of pegmatites, if viewed in this way, primarily reflects a very strong reduction in the number of growth centres, leaving considerations of eventual variations in growing rate and available time aside. Growth centres are provided by already existing crystals and newly formed crystal germs. Considerations of available energy and observations of actual textures both suggest that germination is most important during the earliest stages of consolidation, mainly in the granitoid zone, whereas in later stages crystal growth concentrates mainly on the surfaces of already existing crystals. The number of growth centres is further reduced by the exclusion of unfavourably situated or orientated crystals, which are overgrown by others. This finally leads to a limited crop of huge, more or less orientated crystals. All this may in many respects be compared with the development of comb structures in hydrothermal veins.

The difficulty of forming crystal germs also explains the marked mineralogical fractionation within pegmatites. Crystal growth of already existing phases will be favoured, and among these probably those phases of least solubility and greatest concentration will grow faster than the others. This leads to an early relative concentration of the more insoluble component in the solid phase coupled with an elimination of it from the disordered phase, i.e. from later crystallizations. It may be illustrated by the relations between oligoclase and microcline. Another aspect of the same phenomenon is the growth of one constituent, such as biotite, in advance of the bulk mass of minerals. This is evidenced by the strong folding and distortion sometimes observed in biotite flakes, which are surrounded by undisturbed feldspar and quartz. This at the same time proves that all minerals in a given zone did not crystallize simultaneously.

The characteristic attachment of minor minerals, such as garnet, magnetite, apatite, zircon, fergusonite, yttrotantalite, gadolinite, xenotime, euxenite, etc. on large flakes of biotite, may also be explained on this basis. These biotite flakes originally were surrounded by non-crystallized matter and acted as a substratum for crystals of the minor minerals, possibly by also providing growth centres. Regarding very common accessory minerals such as zircon, the reverse may also be true, i.e. such crystals may have acted as growth centres for biotite and other minerals grown on it. Other combination textures, graphic granite for instance, can likewise be regarded as expressions of the general scarcity of growth centres and the difficulty of germ-formation.

Finally consider the case of a component, the concentration of which gradually rises during consolidation of the bulk of the pegmatite, thus ultimately reaching saturation. If it can form no crystal germs, nor make use of growth centres provided by already existing phases it may be expected to reach a certain stage of supersaturation before crystallization starts. On the other hand, once crystallization has started it may proceed very rapidly, giving rise to concentrated masses of rather fine grain, or, if the component is rare and rather insoluble, it may form small highly localized concentrations, often represented by giant single crystals. The first alternative may apply to those masses of sugar-grained albite, which are not clearly of replacement origin. In these cases the sudden opening of fractures may have initiated crystallization. The second possibility may apply to many core margin crystals, whose formation was delayed until the main crystallization of microcline had ceased. An intermediate position possibly is represented by masses of tourmaline and spodumene, which minerals sometimes show a sudden, fine-grained onset of crystallization, which rapidly develops into the formation of large prismatic logs. This is supposed to be a repetition of the general mechanism of increase in crystal size which was likened to the development of comb structure in hydrothermal veins. An extraordinarily instructive photograph of spodumene of this type is given by CAMERON *et al.* (loc. cit.).

In conclusion it may be stated that pegmatites differ from ordinary igneous, or igneous-looking, rocks in that crystallization did not take place on individual growth centres distributed more or less evenly throughout the crystallizing masses. Instead, at least in the later stages of evolution, growth was, in principle, concentrated on a boundary surface which separated already crystallized matter at the walls from the still disordered phase in the interior. The fractional crystallization at this surface may ideally be likened with chromatography. The critical feature of the process is the anti-kinetic selection of participating ions and groups by the sites of fixation. It is thus essentially non-eutectic and a case of application of Soret's principle.

The Behaviour of Quartz

In the previous section mention was made of the fact that quartz apparently behaved abnormally. The most obviously abnormal feature is its late concentration into the quartz core, which cannot be explained on the basis of low melting point, high solubility or low concentration. Nor is it possible to explain this marked delay of crystallization by the absence in early stages of growth centres, for quartz is an essential constituent both of the granitoid zone and the zone of graphic granite. However, as pointed out in the discussion of the division of pegmatite minerals into paragenetical groups, the zone of graphic granite is limited against younger units by the sudden cessation in the formation of graphically intergrown quartz crystals. This marked break in the crystallization of quartz, especially when contrasted against the quiet continuity in the crystallization of other minerals inclusive that of the microcline host crystals, constitutes an even more startling abnormality in the behaviour of quartz during the crystallization of pegmatite systems. It is rather tempting then, to assume that there is a hidden connection between those two irregularities in the behaviour of quartz. They therefore should rather be treated together, as different aspects of the same general problem. The graphic granite itself also poses an independent problem of its own genetical significance, which has been much discussed and which must therefore be briefly considered first.

In concurrence with most earlier investigators, notably FERSMAN (1928), the present writer is of the opinion that graphic granite represents a product of simultaneous crystallization. Two more recent, major contributions to the subject by WAHLSTRÖM (1939) and by DRESCHER-KADEN (1948), seem to suggest that graphic granite is no such product but instead was formed by replacement, i.e. that quartz replaced the host feldspar crystals along some preferred directions. This interpretation, however, is definitely excluded by a consideration of the zonal distribution of graphic granite in zoned pegmatite bodies, together with the fact that crystallization as a rule started near the walls and proceeded inward, and that "graphic granite" crystals can be found to be surrounded by a crystallographically continuous non-graphic microcline shell. These shells are systematically found on the core-ward side of the crystals. If the interpretation given by WAHLSTRÖM and DRESCHER-KADEN should be correct, it would require the opposite to be found, namely that replacement had attacked the core-ward portions of the microclines first. Probably the two petrographers have been misled by not observing macroscopically the zonal position of the graphic granite and likewise not being able to discriminate between graphic granite *sensu strictu* (e.g. as defined by FERSMAN), and other, similar-looking quartz-feldspar intergrowths found in pegmatites and granites. (WAHLSTRÖM, loc. cit. also includes intergrowths of other minerals into his consideration.) Furthermore some of their arguments are based on textural features, the interpretation of which may be ambiguous. Later investigations by HERITSCH (1953) have shown that in some cases the optical orientation of the quartz in graphic granite has been changed from its original direction by later strain.

A return may now be made to the question as to why quartz of the graphic granite stops growing, a feature which by itself speaks against later quartz-replacement. There are primarily three answers, namely:

1) There was no more silica to crystallize;

2) The silica was mobilized, i.e. the mobility of the silica was increased so that its tendency to form a solid phase was reduced;

3) The silica was immobilized, i.e. the mobility of the silica was reduced so its ability to order itself into crystallized quartz could not balance the growth-rate of host microcline.

The first alternative can be definitely excluded from consideration, for the great masses of quartz in the quartz cores provide ample evidence that pegmatite systems were far from exhausted in silica in earlier stages. In the second alternative, mobilization might imply a raise in temperature, which is improbable, or increased solution. Of eventual solvents HF or fluorides, H_2O, and alkalis seem the most probable ones, but even these have to be discarded. Thus, if fluorides were the critical agents one should find zoned pegmatites in limestone surrounded by much fluorite as illustrated by the following formula:

$$SiF_4 + 2CaCO_3 \rightarrow 2CaF_2 + SiO_2 + 2CO_2.$$

It was also already indicated in an earlier section that it is improbable that a quantity of alkalis and water sufficient to keep in solution a mass of silica in proportion to a normal quartz core once had been present in a pegmatite body and later left it without leaving any evidence of this. Apparently therefore there only remains the third alternative, that the mobility of silica was reduced at the end of the graphic-granite stage.

Regarding the cause for this reduction in mobility one may ask whether the loss of thermal energy alone can account for the effect in question. It should rather give rise to a continuous and gradual reduction of quartz in graphic granite, whereas, as shown, the break is marked and sharp. Water has been repeatedly suggested as a possible agent for causing disturbances in the crystallization of quartz, but it is difficult to see how, exactly, it could cause the observed effects. Further, if presence of muscovite is taken as an indicator of water activity in pegmatite systems, it follows from identical behaviour of quartz in pegmatites with, and without muscovite, that water alone is not a decisive factor in this connection. Instead it is suggested that attention be focussed on the possible rôle of carbon dioxide. Its action may be schematically described by the following formula:

$$SiO_3^{2-} + CO_2 \longleftrightarrow SiO_2 + CO_3^{2-}$$

This formula is a general expression of a number of important geochemical reactions, among these we may note the wollastonite-calcite equilibrium, cf. DANIELSON (1950). Heat is known by experiments to displace the equilibrium from right to left. Thus, in a pegmatite system, which is cooling in a closed space, reaction will proceed from left to right. By the gradual solidification of the pegmatite the CO_2-pressure will increase in the residual system, and it will force the reaction in this direction. This means that silicate ions, which are highly mobile (for instance when balanced by sodium or potassium ions), will be transformed into less soluble and mobile silica by the action of carbon dioxide, which changes into carbonate ions.

The process may be pictured as taking place over intermediate steps of increased polymerization in the silicate-groups leading finally to the precipitation of silica. The net result along these lines of reasoning is that a stage may be reached where precipitation is so fast, or the silica-groups in the system are so large and immobile, that the ordering into quartz crystals can not keep pace, so the development of graphic granite ceases, and a kind of dispersed silica is developed.

In order to avoid misunderstandings it should be pointed out that the suggestion of carbon dioxide as a critical factor in this process does not imply that alkalis and water are not essential in depressing the melting point of quartz in pegmatite systems or that the loss of thermal energy does not contribute to the polymerization or aggregation of the silica. However, if there is need for an additional factor to explain the sudden stop in the development of graphic granite, as there seems to be, then carbon dioxide seems to meet the requirements, for it may be expected both to be present in pegmatite systems and to work in the desired direction. Furthermore, those pegmatite bodies, which in most respects, such as mineral composition or grain size are equivalent to first group pegmatites, but which differ from these by being composed of graphic granite even in their central parts, may thus be readily explained. They represent the solidification products of granitic pegmatite systems, which were poor in, or entirely devoid of, carbon dioxide.

It is difficult to assess the actual conditions in a pegmatite system and the true constitution of matter at this hypothetical stage in its development. Part of the silica in it will be inert, but not crystallized, whereas other mineral constituents are able to diffuse rather freely in the system towards the walls, where they crystallize. At the end of this stage all mineral matter will be crystallized and the silica gathered at the central part of the body thus ultimately forming the quartz core. Water with dissolved alkali-carbonates and other solutes and excessive carbon dioxide probably will leave the system more or less continuously through fractures in the solid shell, which form whenever the internal pressure of the system exceeds a certain limit.

The entire process may be likened to what happens in a rather concentrated solution of alkali-silicates, with other minor constituents, upon acidification. (Carbon dioxide clearly is playing the rôle of the acid, whereas part of the dissociation caused by the water and alkali in the solution is, in the pegmatite system, effected by heat, which thus partially substitutes for these solvents.) A silica gel is formed, which, however, has no very marked effects on the other constituents of the solution. If the concentrations of these are made to exceed their solubility products, as by evaporation of water or decreasing temperature, or a combination of the two, the solutes will crystallize. If there is a gradient in temperature and water content, such that they decrease towards the periphery, crystallization will be preferentially localized there. This necessitates no special agents or avenues and spaces for material transfer, it is simply an exchange of site, which is aided by diffusion of the solutes and eventually also by the plasticity of the silica gel. One probable effect of the silica gel may, however, be noted. It is well-known that the formation of large crystals is greatly aided by the presence of this gel, and many insoluble substances which otherwise form colloidal precipitates have been thus prepared in microscopic and even macroscopic crystals. Similar effects are also shown by other gels or substances with giant molecules, often when present even in very small concentrations, and they have been applied in various branches of industrial crystallization processes. They may possibly be explained as being caused by some kind of preferential adsorption of the "giant molecules" on foreign growth centres, which are thereby inactivated. Similar effects may, in pegmatite deposits, contribute to the development of giant crystals in core margin associations.

Direct experimental evidence in support of the proposed hypothesis seems to be lacking, but this may be due to the fact that interest in hydrothermal synthesis has been focussed upon determination of stability fields of crystalline phases under stationary conditions. Only most recently have publications relating to work with temperature gradients appeared. What will happen even in a simplified pegmatite system under conditions duplicating increasing CO_2-pressure in the begin, and final gradual expulsion of a quantitatively subordinate, but very important, aqueous phase seems to be unexplored by experiment. It can only be anticipated through theoretical deductions and reasoning by analogy as was attempted at above, and the supposed intervention of a poorly defined, colloid-like and metastabile silica phase can hardly be proved by thermodynamics.

Regarding the colloid chemistry of silica there exists an ever increasing vast body of information. Most of it, however, relates to temperatures lower than those accepted to prevail in pegmatite systems. In recent discussion of some surprisingly high apparent solubility data and transfer rates of silica in water and steam at corresponding temperatures, reference has repeatedly been made to the possible rôle of colloidal solutions. No actual proofs, so far, have been given, and, furthermore, all this refers to much more dilute systems than pegmatitic ones. It must, however, be pointed out that quite generally the difficulty with silica even at these elevated temperatures, is not to prepare it in metastable, colloid or glassy form, but to prepare it in the form of macrocrystalline quartz.

Finally it remains to compare this hypothesis with the features actually found in granitic pegmatites. The hypothesis was devised to explain the cessation in the development of graphic granite and the late concentration of quartz into the core. A number of additional independent features likewise seem to find a ready explanation by it. Here belong all the peculiar textural relations which are found to exist between the core quartz and minerals of the core margin group and some late, fracture-filling mineralizations. They were briefly outlined in a descriptive section. It is only necessary to recall that core margin minerals project into the core in euhedral crystals as if it was an open space. Nevertheless they are sometimes bent and broken, and the core quartz has been able to support and keep in place fragments and also to fill the fractures. In Högsbo fragments of microcline visually estimated to weigh about one hundred kilograms are supported in this way, and also large crystals of beryl of about the same size seem to be thus floating in the quartz, cf. Fig. 24. This combination of stiffness and plasticity may well be exhibited by a gel-like aggregate of silica.

Inclusions of liquid and gaseous carbon dioxide in pegmatite quartz have been described many times, e.g. by Bastin (1911) and Lacroix (1922). That the silica is now found in the form of quartz clearly can be explained by somewhat later crystallization. The quartz crystals often found in cavities in pegmatites show that quartz crystallized already in subsequent stages of pegmatite-development. A striking example, from an entirely different paragenesis, of how a silica gel may recrystallize into quartz has been described by the writer (1955 a).

In summary then it is argued that the behaviour of quartz is characterized by the cessation of its crystallization in graphic granite and its late appearance in the quartz core or equivalent interstitial quartz in the pegmatoid zone and core margin. Fundamentally it may be explained as being caused by the ability of silica to polymerize and to form inert "noncrystalline" matter such as glass and silica gel. A hypothesis, implying a rapidly increased production of silica due to the increased concentration and activity of carbon dioxide in the later stages of pegmatite-development, is proposed.

The Alkali Replacements

The rôle of replacement processes in the formation of pegmatites has received much attention. It would seem that many minor replacements can be regarded as occasional reversions in the nearly reversible crystallization of the later stages in pegmatite consolidation, or as effects of normal reactions between the solid phases and the residual liquid. At times when the replacement theory of pegmatite genesis was most popular a replacement origin was unreflectively assigned also to many minerals where closer investigation of textural relations would have indicated that critical features were due to processes such as slight brecciation and sequential or simultaneous crystallization. In spite of this it cannot be denied that rather radical and important replacement processes are evidenced in some pegmatite deposits. These replacements comprise the formation of muscovite, albite, spodumene and petalite at the expense of microcline. Typical textures are illustrated by Figs. 11, 21, 22.

This type of replacements may be formally treated as representing an exchange or sodium- and lithium ions for those of potassium and it is here discussed under the heading of alkali replacements. (The formation of muscovite, as stated before, implies hydration and extraction of potassium and silica.) Alkali replacements are of a rather systematic occurrence in the sequence of paragenetical groups, and often are developed on a remarkable scale, which in the case of spodumene and petalite is of great economic importance. It cannot, therefore, be referred to the class of occasional and small scale features in the crystallization of pegmatites. Likewise it cannot be considered as a normal extension of Bowen's reaction series, for potassium is actually released in the process, whereas according to the reaction principle crystallized matter stays in the solid phase. Textural features, especially grain size, seem to speak against an interpretation solely implying a sudden release of supersaturation, which, however, may be responsible for the formation of some masses of sugar-grained albite, and might also constitute an important contributing factor in the formation of other alkali replacements.

Another aspect of the problem posed by the alkali replacement is the potassium balance. It is true that in many pegmatite bodies with only minor formation of late albite, simultaneous formation of muscovite seems capable of consuming most of the potassium made available by the replacement exchange. In many larger lithium deposits, however, microcline is replaced to such a large extent that simultaneously or later formed mica is insufficient as a repository for the potassium thus released in the replacement process. The conclusion that potassium actually left the pegmatite system during this stage therefore seems unescapable.

If this conclusion is accepted the next step of the deduction should consider the possible means for such an expulsion of potassium from the pegmatite system. If earlier deductions and the general assumptions of this interpretation are considered it would seem most likely that the potassium left the pegmatite system in the form of soluble compounds together with the volatiles, i.e. water and carbon dioxide. This could be termed an aqueous solution of potassium carbonate (and other disolved solids), if considerations of the physical state or aggregation of the matter are left aside. It may be remarked that in this connection there seems to be no point in discussing whether the separation of volatiles was achieved through resurgent boiling, squeezing or any other feasible mechanism. This depends on local conditions in the surrounding rocks and may have varied in different deposits as well as in time at one and the same deposit. (The inapplicability of resurgent boiling within pegmatite bodies, on the other hand, has been discussed earlier.) Independently the above conclusions seem to be in good agreement with the observations on wall rock alteration around zoned granitic pegmatites.

The relations between the residual pegmatite system and the fugitive system of volatiles can be regarded as those of a system of two separable solvent phases, which has earlier been analyzed by NEUMANN (1948). The distribution at equilibrium conditions of a component between the two phases is governed by its respective solubility in each of them. Considering the solubility of alkali-carbonates in an aqueous phase it is found that potassium carbonate is much more soluble in water than the corresponding salts of sodium and lithium, the difference amounting to one and two orders of magnitude. If the potassium content of the residual pegmatitic system has earlier been exhausted by the fractional crystallization of microcline and the sum of alkalies present exceeds the amount needed for the formation of feldspar and corresponding alkali-alumosilicates, some of the potassium will again be solvated and mobilized in contact with the newly formed carbonated aqueous phase. It thus appears that the separation and escape of volatiles would tend to deprive the residual pegmatite system of its potassium content, and thereby cause the change in stability relations of the alkali-alumosilicates, which is manifested by the alkali replacements.

Direct experimental verification of this process is not at hand, but experiments on accelerated weathering of feldspars clearly indicate the reduced stability of K-feldspar in comparison to that of albite under rather similar conditions regarding temperature, and the influence of water and carbon-dioxide, NORTON (1937). The localization of replacement minerals should accordingly reflect the avenues of escape, i.e. generally trend from the core, through earlier crystallized zonal shells, into the surroundings.

The process deduced and outlined here clearly might account for the formation of albite, spodumene, and petalite at the expense of microcline, i.e. the exchange of Na^+ and Li^+ for K^+. In contrast it is not applicable to the larger alkali ions, Rb^+ and Cs^+, for their carbonates also are very soluble in water, and they should therefore be expected to behave like potassium. This seems to be the case with rubidium, which is often concentrated in late microcline. The delay is probably due to its originally lower concentration in the pegmatite system and its larger ionic radius, in comparison with potassium. Caesium, however, forms a mineral of its own, namely pollucite, and its paragenetical relations are more problematic.

Pollucite is a rare mineral, and information on its occurrence seems to be insufficient for the present purpose. Furthermore it has not been possible to the writer to settle the problem by direct observations at Varuträsk, where the mineral occurs abundantly, but in places which are now inaccessible. Printed information regarding this deposit seems to indicate that the mineral formed during a stage of caesium replacement, intermediate, in time, between earlier lithium replacement and later sodium replacement, QUENSEL (1956). This is based on the statement that the mineral replaces petalite, which is, however, not directly evident from accompanying illustrations. On the contrary, a sketchmap, after E. Grip, said to illustrate this relation, may rather be taken to demonstrate that the pollucite occurs as rounded fragments enclosed in petalite. On the other hand the occurrence of pollucite also is likened to that of (core margin) amblygonite, QUENSEL (1938). The fact that the pollucite is veined both by spodumene and albite might likewise indicate that it actually belongs to the core margin group and antedates both the sodium- and the lithium replacements.

Since there is no immediate possibility of settling this question it can only be stated that if pollucite should belong to the core margin group this would hardly imply anything new in principle, but would be another example of the late crystallization of rare components and thus be comparable to the formation of core margin spodumene or amblygonite. A late-stage formation of pollucite, partially at the expense of petalite, would, however, mark a less orderly evolution. It might indicate a temporary break in the exchange of alkali ions, which could result from a stop in the escape of volatiles. In this respect it may be compared to the late formation of some muscovite, which is not a very rare feature in many complex pegmatite bodies. Both mineralizations imply a fixation of the large alkali ions and a hydration due to the increased activity of water. The latter would also decrease the stability of petalite and favour the formation of lepidolite. The zeolitic affinities of the pollucite lattice can also be taken as an indication of increased stability during more properly hydrothermal conditions.

Extension of the Interpretation

The interpretation suggested in the preceding sections is an attempt to explain the sequence of major constituents and some of their textural characteristics as found in pegmatite deposits showing a general conformance with the basic zonal pattern. To this end four fundamental principles were proposed, namely fractional crystallization due to the heat loss through the walls and the scarcity of crystal germs and growth centres;

hydration and solvation due to the increasing activity of water in the course of the solidification of the pegmatite system, and

acidification due to similarly increasing activity of carbon dioxide. In the following two sections an attempt will be made to explain the existing alternative type of systematic zonal sequence and the distribution of acessory or minor minerals on the basis of the same principles.

The Reversed, or "American" Zonal Pattern

As will be recalled from the descriptive section there exists a zonal pattern in granitic pegmatites, which differs from the one which was chosen as a norm in the present paper and forms the basis of the preceding interpretation. This different pattern has been chosen as a norm especially in recent American literature on granitic pegmatites, and may therefore be called the American type of zoning. It is characterized by outer zones in which muscovite and quartz are dominant phases, whereas microcline is surpressed. In this respect as well as in the association of minor minerals, such as beryl, tourmaline, columbite, and cassiterite, the outer zones of this pattern resemble the normal core and core margin. Later stages in the development of pegmatites of this kind are the same as in those with this paper's normal sequence of zonal units. For these reasons the special pattern also was termed reversed zoning in earlier sections. The problem of the "American" zonal pattern therefore is to find an explanation of this reversal in outer zones and the gradual attainment of normal zoning.

In the present interpretation the core and core margin associations of major constituents showed the influence of the increased activity of water and carbon dioxide, which at this stage had become important constituents of the residual pegmatite system through the crystallization of mineral matter. If, however, the pegmatite system had been correspondingly charged with these volatiles already at the moment of emplacement, similar mineral associations should appear in the early stages of consolidation. Gradual loss of volatiles to the surroundings by effusion, diffusion or even resurgent boiling, would again promote the formation of intermediate zonal units. When further loss of volatiles is prevented, they may again accumulate and thus lead to the formation of a normal core, core margin, and other late paragenetical groups.

The Distribution of Minor Minerals and the Later Stages of Paragenetical Development

The distribution of minor constituents will be discussed on the basis of the earlier division into paragenetical groups. Throughout the discussion it must be remembered that the occurrence and proper sequential place of each mineral is determined not only by general rules but also by the specific concentration in the individual deposit. This has been earlier exemplified by the varying occurrence of tourmaline. In spite of this, rules seem to exist which express common findings of minor constituents in granitic pegmatites.

Thus in the earliest zones of the normal pattern noteworthy rarer minerals are seldomly found. Small-sized accessory minerals are the same as found in granitic rocks in general. In the pegmatoid zone, however, a characteristic suite of pegmatite minerals is found. It may be subdivided into an earlier and a later group. The earlier group comprises oxidic minerals such as complex titanates, tantalates, and niobates of the rare earths (especially the Y-group), with some iron and calcium; phosphates such as xenotime, monazite, and apatite; minerals of the zircon group; and allanite and gadolinite. All these minerals are characteristically composed of strongly charged ions, which should be favoured in the competition for sites of fixation and the formation of crystal germs. As already mentioned, the crystallization of many of these minerals is further promoted by the apparent ability to grow on biotite. Clearly the same factor, which controlled fractionation among major constituents in this zone, also was effective in the precipitation of these accessories.

The later group of minor minerals in the pegmatoid zone first reaches ideal development in the paragenetical group of the core margin. Thus in the pegmatoid zone it only denotes that conditions were gradually changing to those characterizing the core margin. From the behaviour of quartz and of muscovite it has been concluded in an earlier section that water and carbon dioxide were increasingly important at this stage, and that the formation of the core margin group should be marked by the combined effects of solvation, hydration, and acidification. The immobilisation and precipitation of inert silica, which is a consequence of acidification, should further result in a marked reduction of the still mobile part of the pegmatite system. This means that those constituents, whose crystallization was earlier delayed because of their low concentration, become now correspondingly concentrated (1). In addition the partial exclusion of silicate ions from kinetic competition should promote the crystallization of compounds with other anions (2). Finally, aqueous solvation of strongly dissociated components should stabilize compounds with ampholytic properties (3). Typical members of the core margin group consequently should be products of anyone of these effects or combinations thereof. Thus beryl is a combination of (1) and (3); tourmaline, triplite, monazite, amblygonite, columbite, and samarskite of (1) and (2). If the process continues, (1) may also lead to the crystallization at this stage of albite and spodumene, and (2) and (3) combine in the formation of beryllophospates.

The next stage of mineralization would be the alkali-replacement group proper. This represents the same conditions, but of increased intensity. Here probably acidification has gone so far that cassiterite is precipitated in spite of its small concentration, further (2) leads to the formation of microlite.

If there was an original excess of volatiles, these may, after the content of alkalis in the system has been exhausted, promote a stage of solvation and hydration. This preferentially attacks the alkali-alumosilicates, which are first transformed into core margin mica. Most earlier accessories remain stable during this stage. Chrysoberyl eventually forms at this stage, as a further consequence of (3). On further extraction of alkalies and at a lower temperature, typical clay minerals are formed.

Additional Aspects

A well-rounded picture of zoned granitic pegmatites should include much more than a mere outline of their mineralization. It should treat the processes which lead to their origin and indicate the main principles which govern their evolution. Likewise, the differentiation of granitic pegmatites into groups of different mineralogical and chemical composition should be analyzed. The structural behaviour of pegmatite bodies ought also to be reviewed and eventually also analogies with other types of mineral associations and deposits should be discussed. However, a treatment, even in outline of these and other aspects would require a full paper of its own. In order to provide a moderate conceptual background to the central parts of the present paper some brief statements on these aspects will nevertheless be given here. These statements represent in part less consolidated ideas of the author, which is due to their peripheral nature.

Origin of Pegmatites and their Combination of Elements

One mode of origin of granitic pegmatites may be exemplified by the relationships at Baveno. Here, as mentioned before, a stock of granite is surrounded by a zone of contact metamorphism and is clearly intrusive into sedimentary rocks. Within the granite occur numerous bodies of pegmatite in the form of rather irregular stringers, schlieren, and lenses, many of which contain large central cavities. Evidently a magmatic approach towards these facts seems most appropriate, and the entire set-up may be likened to what is seen in a pot of boiling porridge with its rising steam-bubbles.

The forces which provoke the migration of water toward the top portion of stock-like intrusives and its accumulation there, that is in areas of reduced pressure and temperature, have been discussed more formally by KENNEDY (1955). His treatment may also be extended to the case of carbon dioxide and other volatiles. Naturally their accumulation will be accompanied by that of low melting components of the granite, especially those, whose melting point is strongly depressed by water. Another important aspect, pointed out by GOLDSCHMIDT (1930, 1937), is that pegmatite systems are enriched in components rejected in the crystallization of the common minerals of granites.

In metamorphism carbon dioxide and water will likewise accumulate in areas of reduced pressure (and temperature). If they are allowed to reach equilibrium with surrounding silicate rocks at pegmatitic temperatures pegmatite systems should be formed, which in bulk chemistry and general properties must be nearly identical with those of directly magmatic origin. On crystallization the volatiles are again set free, and thus act like catalysts which are not consumed in pegmatite formation. Consequently relatively small amounts of volatiles may be expected to give rise to sucessively larger numbers of pegmatite bodies within a given volume of country rock. However, a very great number of pegmatite dykes, as in veined gneisses, would indicate rapid shifts in the loci of reduced pressure, and such tectonic unrest would not be favourable for the development of clear zoning. Well-zoned pegmatites therefore should belong to the late stages in this development. It may be remarked that this migratory catalytic action in certain respects makes a distinction between magmatic and metamorphic origin of granitic pegmatites artificial. (On the other hand the present interpretation of crystallization in zoned pegmatite bodies seems to necessitate that the bulk matter of these pegmatites in the place of crystallization did pass a disordered stage which is best described as a magmatic one.)

Differentiation of Granitic Pegmatites

Differentiation of granitic pegmatites, as was illustrated by the grouping in the descriptive part of this paper, is manifested mainly along two different lines. One line marks changes in the activity and nature of volatiles in the pegmatite system as evidenced by the appearance of specific mineralizations in the following series: muscovite (H_2O), alkali replacements (CO_2?) and topaz/fluorite (HF). The other line marks changes in essential cations and is expressed by the elimination of biotite and the An-component in plagioclases (Mg, Fe, and Ca), the dominance of microcline (K) and the increased rôle of late albite and Li-minerals (Na, Li). These two lines of differentiation are found to run parallel only partially. Thus there are found deposits which independently represent end products of each line, e.g. pegmatites rich in topaz and fluorite without special enrichment in the rarer alkalis; and marked alkali-rich pegmatites poor in fluorine minerals.

The first line of differentiation seems to be a function of depth. In sections representing high levels of intrusion pegmatites rich in volatiles are more common, whereas simple pegmatites with biotite prevail in areas of greater original depth. Presumably this should be explained in accordance with KENNEDY's discussion on the distribution of water, for a concentration of volatiles in the higher levels must be coupled with a corresponding impoverishment in depth.

The differentiation in essential cations is more complicated. The elimination of Mg, Fe, and Ca can easily be accounted for as an effect of ordinary fractionation by crystallization. (In passing it may be remarked that this elimination can be the cause of the increased importance of accessory Mn in late-stage pegmatites.) However, it is believed that excess alkali cannot be derived from normal granitic rocks by crystallization differentiation, for if these rocks were originally saturated in alkali all their mica would have been converted into feldspar and alkali-amphiboles. A possible mechanism is suggested by a consideration of the following formulae:

$$CO_3^{--} + SiO_2 \longleftrightarrow SiO_3^{--} + CO_2;$$

$$H_2O + 2F^- + SiO_2 \longleftrightarrow SiO_3^{--} + 2HF;$$

Thus, at high confining pressures the most probable phases are carbonates and fluorides, which as fluxes will be concentrated into the residual systems by fractional crystallization. Electroneutrality will be provided by the positive charges of alkali ions. On migration toward higher levels and the sites of final deposition (e.g. loci of reduced pressure) a gradual change into undissociated volatiles takes place, as indicated by the right hand terms, with their increase in volume. Now electroneutrality is secured by extraction of anion-forming groups (oxides) from the surroundings. As already detailed in the discussion on the mineralizations in pegmatites, the entire process will be reversed and the oxides precipitated when the pressure of the volatiles is again increased by the crystallization of mineral matter (normal zoning), or by tectonic pressure at the moment when the mobile pegmatite system is trapped at its final site ("American" zoning).

Apart from giving a mechanism for the enrichment in alkalis this principle may also illuminate other aspects and trends. The extraction of acid forming oxides thus explains why columbite-tantalite and cassiterite mineralizations often are combined with albite and spodumene, i.e. alkali-mineralizations. Further, both the concentration of alkalis and that of water and fluorides tend to lower the melting point and reduce the viscosity in silicate systems. A structural basis for this effect has been given by BUERGER (1948). In the end this can be expected to cause a regional zoning as is sometimes found in pegmatite districts.

Structural Behaviour and Relation to Metamorphism

The last sentence leads over to the problems of the structural behaviour of granitic pegmatites. The one problem causing most trouble to some investigators is the apparent contrast in viscosity which is evidenced on the one side by the "absence" of feeding channels and on the other side by the marked disturbances in the wall rock caused by the pegmatite body. Now, feeding channels, also when apparently absent, may be present on a near-microscopic scale. A case, where such minute fracture fillings are of direct practical importance in the prospecting for new muscovite deposits, has been reported on by ROY *et al.* (1939). Further it is known by experiment, WYART and SABATIER (1957), that granitic systems charged with water will be of very low viscosity, so as to form a meniscus in the crucible. Clearly such a system may become rather rigid upon loss of some of its water. Finally, when the high mobility of carbon dioxide and water is considered along the line suggested above (in connection with metamorphic pegmatite-formation), this special problem seems to vanish altogether. It also has, however, a tectonical aspect of some importance. It is generally accepted that tectonic pressure can cause even layers of solid rock to be squeezed into disconnected bodies, provided the surrounding rocks are somewhat plastic (boudinage). Likewise, if one layer of rock is more plastic than the surroundings it will be squeezed into isolated lenses, as is often the case with limestone beds. Consequently there is nothing disturbing in the belief that a plastic body such as a pegmatite magma will show the same relations even more often and clearly. If bodily connections between such lenses are missing this is less surprising than the missing connections between parts of a once continuous limestone layer.

Plasticity in the wall rocks is, indeed, essential for the formation of pegmatite deposits, and this is directly co-ordinated with the essential rôle of volatile constituents. If matter corresponding to a pegmatitic system should be emplaced into an open fracture, then the volatiles would escape and no pegmatitic crystallization could take place. For this reason pegmatite bodies are not found as extrusive rocks or in the clastosphere. In this respect there exists a fundamental analogy and correlation between pegmatites and metamorphism, for in the latter the activity of water is also of prime importance, which was clearly demonstrated by the experiments of YODER (1952), and has since then been much commented on by petrographers.

Analogies with Other Mineralization

Finally there remains to indicate some analogies with other types of mineral associations and deposits. In this respect one might question if the late crystallization of quartz in ordinary granite cannot be discussed along lines similar to those here applied to the core quartz. Likewise the conspicuous correlation between cassiterite, columbite, and tantalite and alkaligranites may depend on a similar mechanism of enrichment as that in pegmatites. Related mineralizations in carbonatites as well as accompanying metasomatic processes, which lead to fenitization, could also imply analogous reactions in a different milieu.

It seems furthermore quite obvious that many greisen deposits are very closely related to the paragenetical groups of the core margin and the core margin mica in zoned granitic pegmatites. Likewise great similarities seem to exist between the core margin mica association and late clay mineralization in pegmatites, and wall rock alterations around sulphide deposits, if the mineralogy of the original material and the final products is considered. Regarding typical hydrothermal mineralizations it will only be indicated here that analytical data on some sulphide- and gold-bearing quartz veins and their wall rocks suggest that they may well have been formed by a partial exchange of CO_2 and SiO_2 between the vein and the wall rock. If it is remembered that the final product which leaves a pegmatite (and granite?) system upon its solidification is believed to be an aqueous solution of alkali-carbonates saturated in silica and carbon dioxide, these brief notes, assumptions, and indications may suffice to show that paragenetical mineralogy opens a wide field of observation, interpretation, and speculation.

Acknowledgements

At the Institute of Mineralogy of the University of Stockholm the writer has had the opportunity to discuss pegmatite problems with his former teacher, Professor P. D. Quensel, to study Quensel's private collection of literature on pegmatites, and also the collection of pegmatite minerals, which, among others, comprises specimens from Southern Norway (part of Brögger's original material); Russia (Mursinka), Sweden, and S. W. Africa (Klein Spitz Kopje), the two latter collections due largely to Quensel himself. Here may be the place to express my deep gratitude to Professor Quensel, for his kindness, helpfulness, and general encouragement.

Thanks are also due to the late Professor G. Aminoff and Professors S. Gavelin, O. Mellis, and F. E. Wickman, for helpful interest in my work, and to Miss S. Gadd, who typed the manuscript, Mr C. Burlin and Mr J. Kutnar, who prepared many of the prints for the illustrations, and Mr R. G. Coyle, who kindly revised the English manuscript. I am also deeply indebted to Dr W. Larsson, for his painstaking checking of the list of references.

My most deeply felt thanks are due to my parents, who with active help, love, impatience, and confidence through a number of years encouraged me not to discontinue my purely scientific work under the burden of more practical duties. In this connection I also wish to thank Dr. E. Grip, Chief geologist of the Boliden Mining Co, for friendful understanding and interest.

The writing of this paper was made possible by the aid of a Doctorand scholarship of the Swedish State, through the University of Stockholm.

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Berggrunden på Riddarskäret i nordöstra Uppland

Av

THOMAS LUNDQVIST

Abstract. Rocks belonging to the Svionian cycle of the Swedish Archean have been mapped and investigated on the small island of Riddarskäret in NE Uppland, Central Sweden. The main rock type is a synorogenic gneiss-granite of granodioritic-quartzdioritic composition, called Uppsala granite. Numerous fragments of amphibolite occur in this granite over the whole area. Sheets of acid supracrustal rocks (leptite) and of banded amphibolites are enclosed in the granite along the planes of schistosity of the latter. The banded amphibolites probably represent basic tuffites and tuffs, possibly also lavas. In the granite a diffuse banding in the direction of strike, possibly derived from highly assimilated supracrustal rocks, is sometimes found. The above rocks are cut by dikes of aplite, granite porphyry and by amphibolite dikes of three different generations, in the directions N80°W, NNW and N70°W, respectively. The youngest rock is a red pegmatite.

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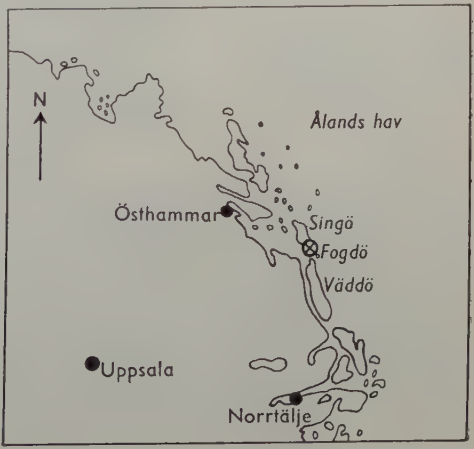


Fig. 1. Nordöstra Uppland. Det undersökta området markerat med ⊗.

NE Uppland. The investigated area is marked ⊗.

Skala 1: 2.3 mill.

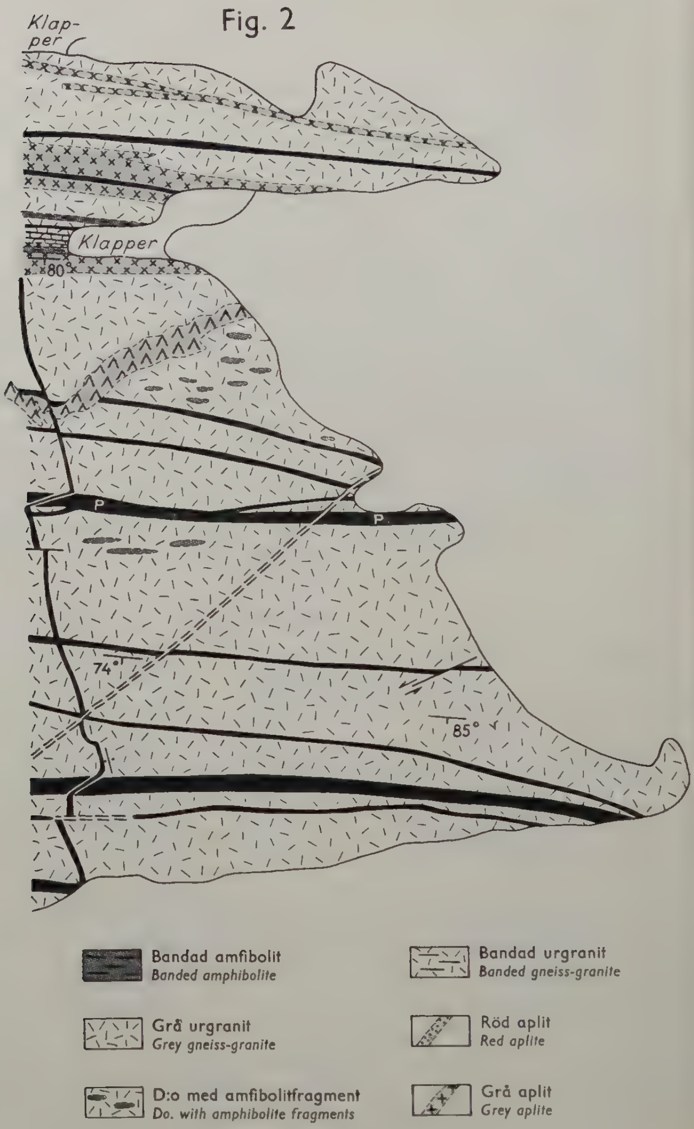


Fig. 2. Områdets läge se fig. 6. — TH. LUNDQVIST del., M. EKMAN cop. *Location see Fig. 6.*

Inledning

Föreliggande undersökning omfattar huvudsakligen östra delen av Riddarskäret, beläget vid bron mellan Singö och Fogdö i nordöstra Uppland (se fig. 1). Berggrundskartering har här under sommaren 1957 utförts i skala 1 : 200. De uppgjorda kartorna (fig. 2—5 och plansch I) utgör ett snitt i N—S, ungefär vinkelrätt mot den allmänna strykningsriktningen för de olika bergartstyperna i området. Fig. 6 (efter ett flygfotografi i skala 1 : 2 100) utvisar de olika detaljkarterade områdenas lägen. Arbetet ingår som led i en större undersökning av Singös berggrund, vilken bedrivs vid Mineralogiska

Fig. 3

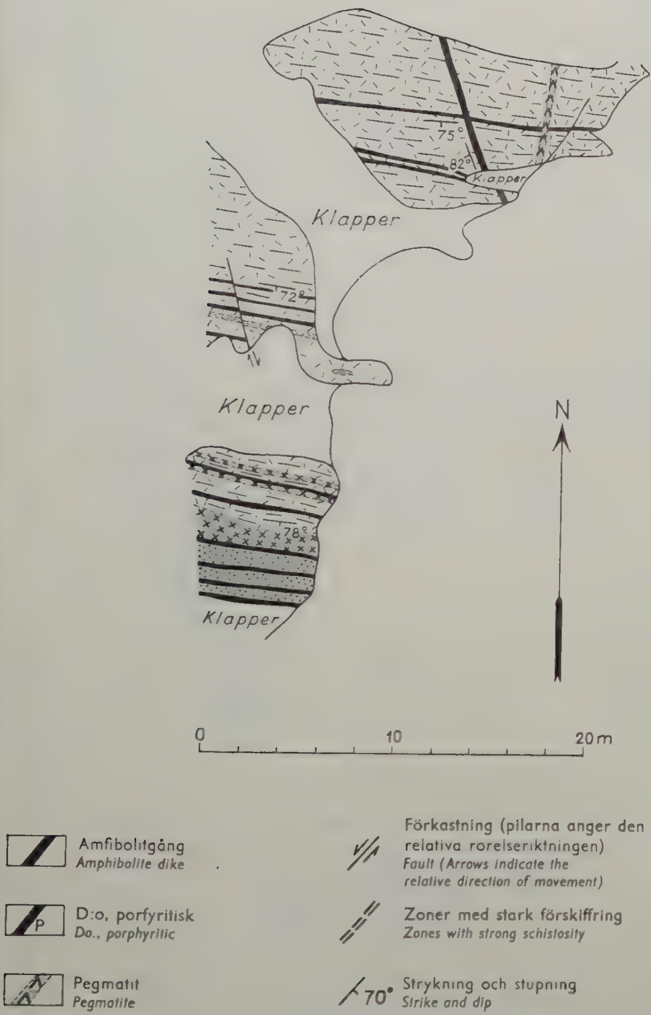

Klapper
75°
82°
Klapper
72°
Klapper
78°
Klapper
N
0
10
20 m
Amfibolitgång
Amphibolite dike
D:o, porfyritisk
Do., porphyritic
P
Pegmatit
Pegmatite
Förkastning (pilarna anger den relativa rorelseriktningen)
Fault (Arrows indicate the relative direction of movement)
Zoner med stark förskiffring
Zones with strong schistosity
70°
Strykning och stupning
Strike and dip

Fig. 3. Områdets läge se fig. 6. — TH. LUNDQVIST del., M. EKMAN cop. *Location see Fig. 6.*

Institutet vid Stockholms Högskola under ledning av professor S. Gavelin. Författaren vill här framföra sitt tack till prof. Gavelin för värdefulla råd och anvisningar under arbetets gång. Till docenten P. H. Lundegårdh vill förf. även rikta ett tack för genomläsning av manuskriptet och diskussion av arbetet.

Huvudsyftet har varit en utredning av relationerna mellan de på Riddarskäret förekommande amfibolitiska bergartstyperna, vilka här väl lämpar sig för studium. Hänsyn har även tagits till förhållandena inom angränsande områden: sydöstra Singö och norra Fogdö.

Fig. 4

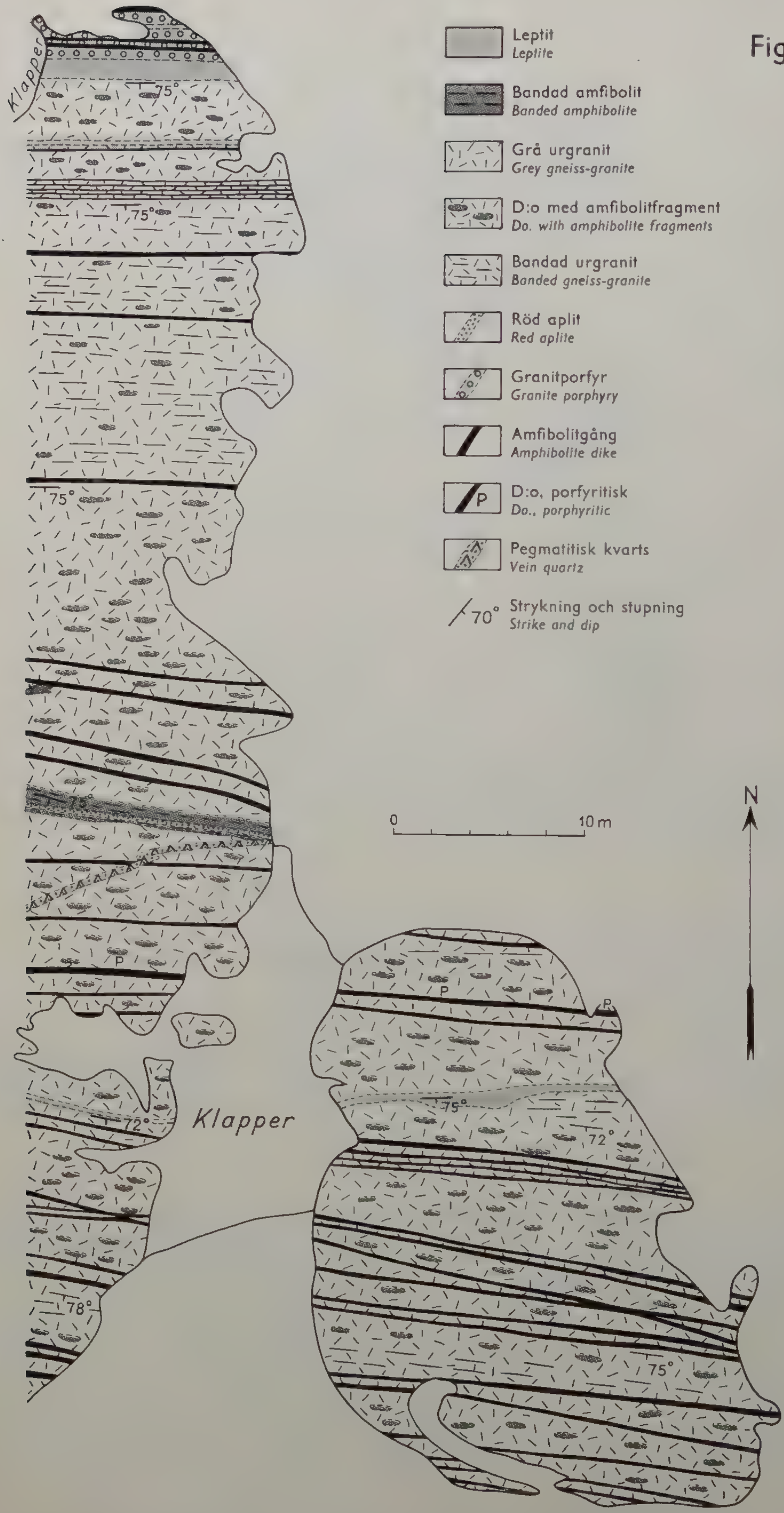


Fig. 4. Områdets läge se fig. 6. — TH. LUNDQVIST del., M. EKMAN cop. *Location see Fig. 6.*

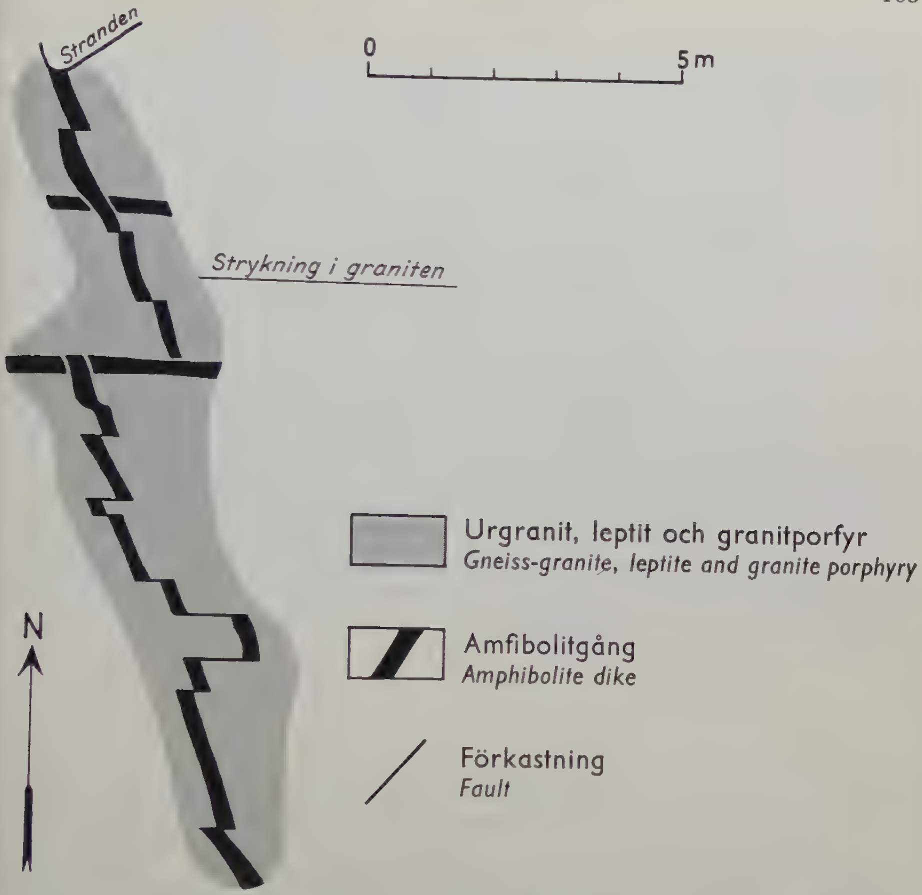


Fig. 5. Visar deformation av NNW-lig amfibolitgång genom glidningar parallellt med granitens skiffrighet. — TH. LUNDQVIST del., M. EKMAN cop.
Amphibolite dike striking NNW, dislocated by movements parallel to the schistosity of the granite.

Allmän översikt över berggrunden

Berggrunden i Riddarskäret—Singö—Fogdöområdet utgör en del av den mellansvenska urgranit-leptitregionen. En översikt av denna har givits av GEIJER och MAGNUSSON (1944). MAGNUSSON (1940) har även givit en beskrivning av det närbelägna Herrängsfältet, vars berggrund har många drag gemensamma med det nu undersökta områdets. Nordöstra Upplands berggrund har behandlats av SUND (1957).

Huvudbergarten på Riddarskäret utgöres av en grå skiffrig granit tillhörande uppsalagranitgruppen. Den innehåller i hela området smärre amfibolitiska brottstycken, utdragna i skiffrighetsriktningen, N80°W. Mera basiska granittyper bildar på några ställen breccior med större, kantiga amfibolitbrottstycken. I graniten påträffas ibland också en diffus bandning.

I gnejsgraniten förekommer vidare konkordant med skiffrigheten liggande skivor av en röd-rödgrå, om leptit påminnande bergart. Grå och röd aplit

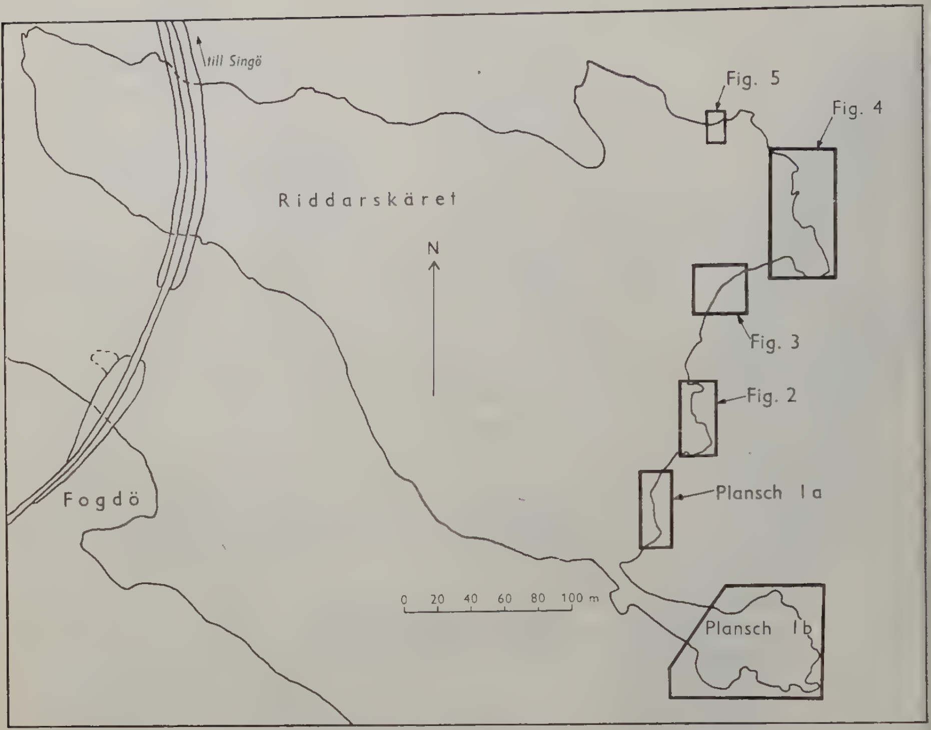


Fig. 6. Visar de olika kartområdenas lägen på Riddarskäret.
The location of the different map areas on the Riddarskäret island.
Fig. 2—6 samt pl. I för spridning godkända i Rikets allmänna kartverk den 24 feb. 1959.

och granitporfyr genomsätter, likaledes konkordant. Dessutom påträffas, särskilt på sydöstra Riddarskäret, talrika skivor av amfibolit, som ligger i granitens skiffrighetsplan och uppvisar en bandning med omväxlande ljusare och mörkare led. Konkordant liggande amfibolitgångar utan sådan bandning utgör även ett markant inslag. Ytterligare förekommer NNW-liga amfibolitgångar, som alltså stryker ungefär vinkelrätt mot de nyssnämnda. Sparsamt representerat är ett gångsystem av amfiboliter, som stryker i en riktning, som endast obetydligt avviker från de konkordanta gångarnas, med dragning åt NW. Slutligen anstår på några få ställen röda pegmatitgångar.

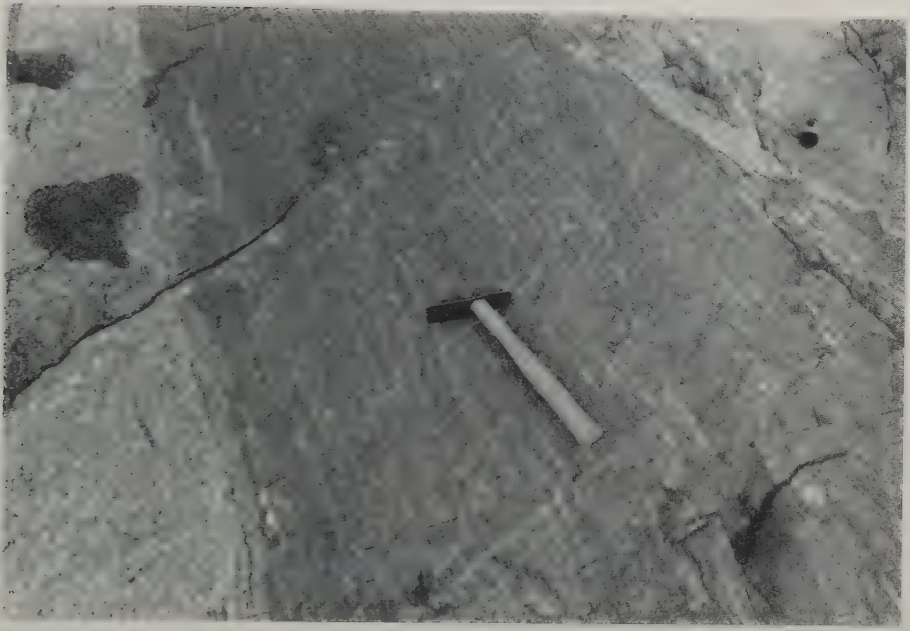
Området är genomdraget av talrika förkastningsplan, dels parallellt med urgranitens skiffrighet, dels parallellt med de NNW-liga amfibolitgångarna.

Petrografisk beskrivning av bergarterna

SUPRAKRUSTALBERGARTER

Leptit

De som leptit betecknade skivorna i urgraniten har en strykning av N80°W—N80°E och en stupning av c:a 75° mot S. De ligger i allmänhet parallellt med granitens skiffrighet. Leptiten är tät, till färgen röd-rödgrå, och visar diffus bandning. Den skiljer sig från nedan beskrivna apliter huvudsakligen



TH. LUNDQVIST 1957.

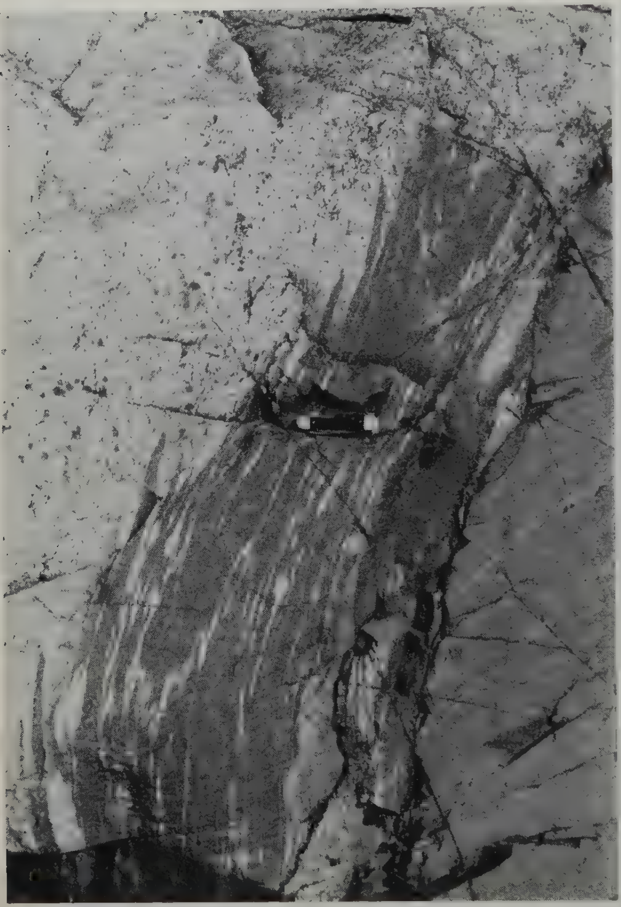
Fig. 7. Bandad amfibolit, genomsatt av amfibolitgång. Södra Riddarskäret.
Banded amphibolite, cut by an amphibolite dike. S Riddarskäret.

genom denna bandning samt genom att den i allmänhet är tätare än apliterna. Då såväl mineralogisk sammansättning som textur- och strukturdrag är mycket lika i de som aplit resp. leptit betecknade bergarterna, kan en entydig karakteristik genomföras främst på grundval av bergarternas geologiska uppträdande i fält. Det bör påpekas, att leptiten uppträder endast på norra delen av Riddarskäret, alltså närmast de norrut på Singö förekommande leptitområdena. Även på sydöstra Singö (på Turhuvudet) påträffas leptitskivor i urgraniten.

Mineralogiskt karakteriseras leptiten främst av mikroklin och kvarts samt sericitiserad plagioklas, den senare till sammansättningen en andesin med c:a 37 % An. Texturen är granoblastisk. Vidare uppträder ibland hornblände i riklig mängd som mörka strimmor i leptiten. Hornbländets optiska egenskaper är följande. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun. Absorption relativt starkt enligt $\gamma \geq \beta > \alpha$. $2V_\alpha$ liten (c:a 40°—50°). $c \wedge \gamma = 15°$, dubbelbrytning = 0.015. Även biotit påträffas. Den visar ibland kloritomvandling. Accessoriskt uppträder apatit, titanit, zirkon och opakmineral. Epidot har bildats genom omvandling av plagioklas. Den innehåller ibland en kärna av ortit. Bland huvudmineralen visar hornbländet ibland begränsning efter {110}-ytorna.

Bandad amfibolit

De bandade amfiboliterna utgör 1 dm—3 m breda skivor, liggande i granitens skiffrighetsplan. De förekommer huvudsakligen på sydöstra Riddarskäret och norra Fogdö. De utgöres av finkorniga till täta, omväxlande ljusa, kvarts-



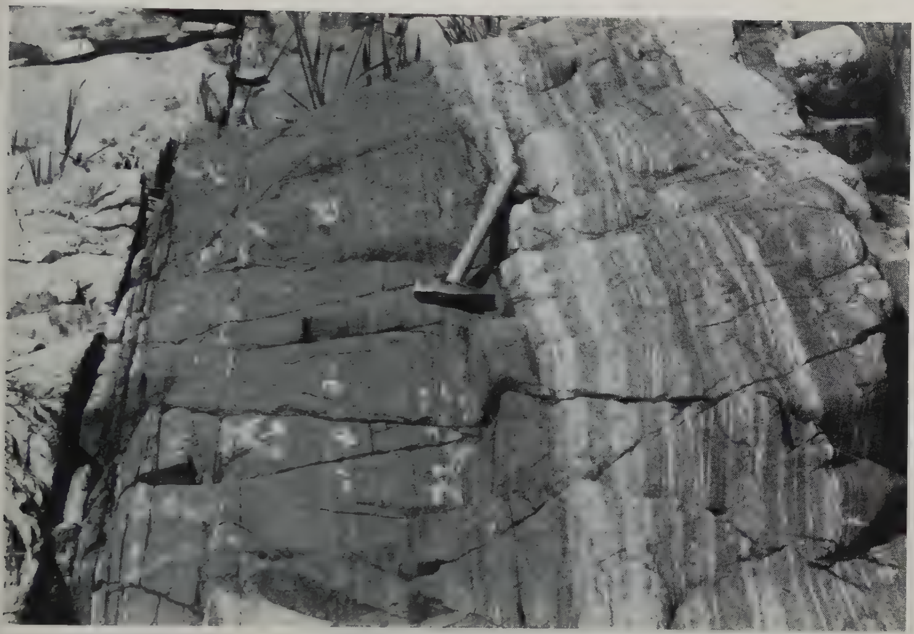
Th. Lundqvist 1957.

Fig. 8. Grå urgranit som bladar upp en äldre amfibolit. T. h. en amfibolitgång. Norra delen av kartan å plansch I b.

Grey gneiss-granite forcing its way into an older amphibolite. On the right, an amphibolite dike. From the northern part of plate I b.

plagioklasrika och mörka, hornbländerika band. Färgen är grå, gröngrå, grönsvart eller svart. I allmänhet är banden några få cm breda, men varierar mellan några få mm till flera dm. Parallellt med bandningen uppträder även aplit samt sura ådror, som i likhet med apliten själv härrör från den omgivande gnejsgraniten. Troligen döljer sig här understundom även yngre amfibolitgångar, men dessa kan ej med säkerhet karakteriseras som gångar utom i de fall, då de skär snett över bandningen, som t. ex. på södra Riddarskäret (se fig. 7).

Vid karteringen har av naturliga skäl endast de typer, som företer ovannämnda växling mellan ljusa och mörka led, med säkerhet kunnat karakteriseras som »bandade amfiboliter». Vissa amfibolitskivor, som saknar denna bandning, kan ju dels tänkas vara isolerade skikt ur en amfibolit av den bandade typen, dels yngre, konkordant liggande gångar (se nedan). Det har således ej varit möjligt att i varje enskilt fall särskilja de äldre och de yngre amfiboliterna vid karteringen, och kartorna ger därför endast en ungefärlig uppfattning om fördelningen av dessa olika typer. I de fall då en amfibolit



Th. Lundqvist 1957.

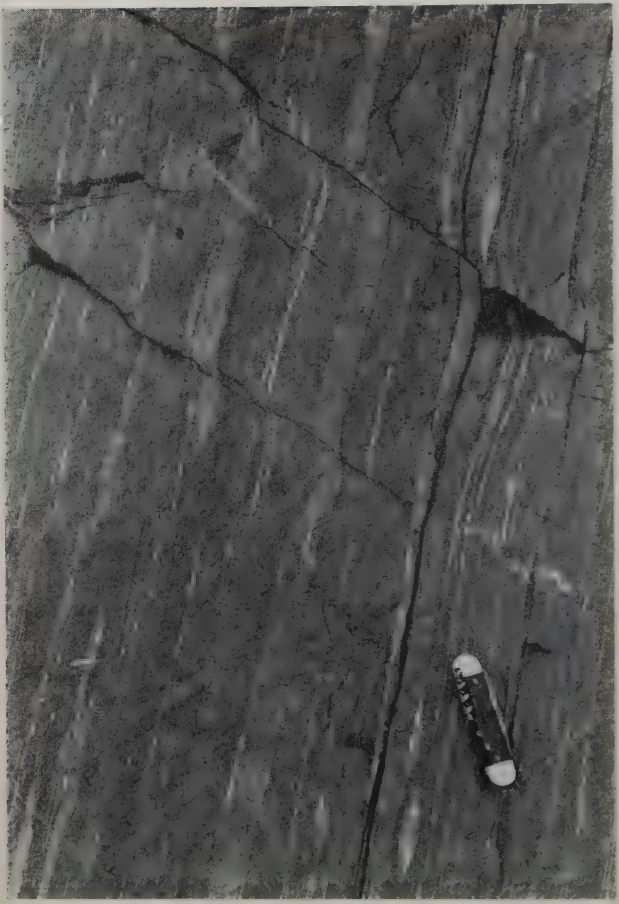
Fig. 9. Bandad amfibolit. På högra delen av fotografiet ingår även grå aplitgångar och urgranit i bandningen. Från området på plansch I a.

Banded amphibolite. On the right hand side of the photograph grey aplite dikes and gneiss-granite are included in the banding. From the map area in plate I a.

av olika skäl, t. ex. på grund av att den »bladas upp» av urgraniten eller innehåller surare ådror från denna (se fig. 8), måste anses vara äldre än graniten, har givetvis också beteckningen för de äldsta amfiboliterna använts. Ett tveksamt fall utgör grönstenen på sydvästra delen av kartan å plansch I b, vilken betecknats som tillhörande de äldsta amfiboliterna. Den brecciering, som här kan iakttagas, kan dels bero på att graniten vid sin intrusion breccierat en äldre amfibolit, dels på sekundära avslitningar av en grönsten antingen av äldre eller av yngre typ. Fig. 9 och 10 visar några typiska bandade amfiboliter.

Mineralogiskt domineras de bandade amfiboliterna av plagioklas och hornblände med varierande mängder biotit och kvarts. Accessorier är titanit, apatit, opakmineral och zirkon. Som omvandlingsmineral uppträder epidot, sericit, klorit och prehnit. Prehniten bildar även sprickfyllnader.

Plagioklasernas sammansättning varierar i de undersökta proven från 42 % An till 56 % An. I de ljusare, plagioklas-kvartsrikare leden varierar plagioklassammansättningen mellan 42 och 45 % An, i de mörkare leden ligger An-halten omkring och över 50 %. Plagioklas förekommer ibland även som större, xenoblastiska strökorn. Sammansättningen av dessa är på grund av stark sericitomvandling och undulös utsläckning omöjlig att exakt bestämma, men An-halten synes ligga omkring eller något högre än halten i övriga plagioklaser. De större plagioklaskornen är någon gång zonerade. Sericitomvand-



Th. Lundqvist 1957.

Fig. 10. Bandad amfibolit. Södra Riddarskäret.
Banded amphibolite. S Riddarskäret.

lingen är då starkast i kärnpartierna. Dessa korn består ofta av ett antal mindre kristaller, som vuxit ihop med något olika orientering. Inneslutningar av kvarts, biotit, hornblände m. m. är vanliga.

Sericitiseringen av plagioklaserna är ofta mycket stark i de hornbländerika leden. Amfiboliten antar då gärna en rödbrun färgton på vittringsytan.

Ett speciellt intresse har ägnats hornbländena. De enda kristallografiska ytor, som finnes utbildade, är ytorna {110}. I övrigt begränsas kornen av mer eller mindre starkt buktande ytor. Tvillingbildning är ytterst sällsynt. Oftast förekommer en tydlig tendens till orientering av de kristallografiska c-axlarna i skiffrighetsplanen. Hornbländena samlar sig ibland till aggregat av större korn, som ger amfiboliten ett porfyritiskt utseende. Dessa korn har samma optiska egenskaper som de övriga. Som inneslutningar i de större hornbländena förekommer huvudsakligen kvarts, opakmineral och titanit.

De optiska egenskaperna för hornbländena är följande. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun-gulgrön, absorption enl. $\gamma \geq \beta > \alpha$. Axelvinkeln ($2V_{\alpha}$) varierar från 44° till 79°. Hornbländena med höga värden på

$2V_\alpha$ visar genomgående en betydligt svagare absorption än de med låga värden. De senare har ofta en mycket stark absorption, vilket försvårar exakta bestämningar av $2V_\alpha$. De höga värdena på axelvinkeln återfinns i regel i de hornbländerikare leden, de låga i plagioklas-kvartsrikare led, ehuru undantag finnes. Parallellt med en ökning av axelvinkeln tycks en svag höjning av dubbelbrytningen och värdet på $c \wedge \gamma$ löpa. Dessa tendenser är dock föga utpräglade. Dubbelbrytningen har uppmätts till 0.017—0.022 och $c \wedge \gamma$ till 13°—17°.

Brytningsindex visar en tydlig tendens att öka då $2V_\alpha$ avtar; se fig. 23 och översikten av hornbländets och biotitens egenskaper och sammansättning (sid. 124).

Biotit förekommer i varierande mängd. Undantagsvis saknas den dock helt. I allmänhet är biotitfjällen väl parallellorienterade. Biotiten visar ofta prehnitomvandling längs spaltytorna. I något enstaka fall har den även gett upphov till blekgrön klorit.

Bestämningar av brytningsindex (n_γ) för biotit i snitt parallella med spaltytorna återges i fig. 23 (sid. 125). Härav framgår att samtidigt som brytningsindex för hornblände minskar, avtar även n_γ för biotit.

Kvartsen är undulös och xenoblastisk. I sällsynta fall kan den förekomma som aggregat av större korn, vilket ger amfiboliten ett kvartsporfyriskt utseende.

Titanit förekommer allmänt, ibland i den för detta mineral typiska kilformen, ibland som rundade korn. Zirkon är gentemot titanit helt underordnad.

Apatit har påträffats i mindre mängd i alla undersökta prover.

Opakmineralen, vilka ej varit föremål för närmare undersökning, ingår i varierande mängd som hypidiomorfa-xenomorfa korn.

Epidot är synnerligen vanlig och förekommer dels som tydlig omvandlingsprodukt ur plagioklas, dels som mer självständiga korn. Ibland innehåller den en kärna av ortit eller isotropiserade nedbrytningsprodukter ur den senare.

INFRAKRUSTALBERGARTER

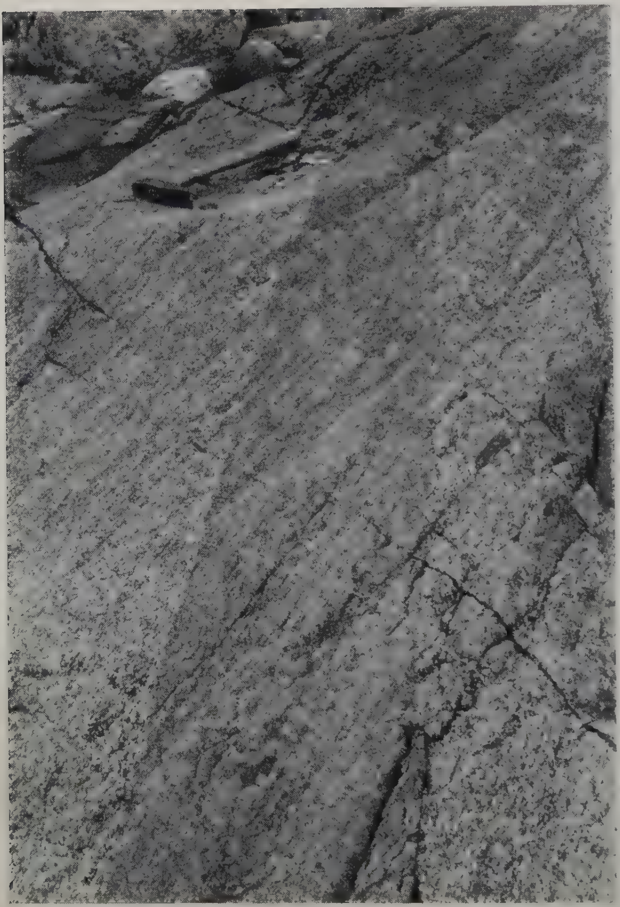
Grå normal urgranit

Den vanligaste typen av urgranit inom området är en grå, medelkornig gnejsgranit av granodioritisk sammansättning. En något mörkare typ förekommer som diffusa band i den förstnämnda graniten. Ibland skär skiffrigheten (N80°W—E—W, stupning c:a 80° mot S) snett över dessa band, så t. ex. på sydöstra Riddarskäret (fig. 11).

På sydöstra Singö påträffas tillsammans med den grå graniten en rödgrå fint medelkornig, intermediär typ av urgranit.

Bland de ingående mineralen i den grå urgraniten dominerar plagioklas (andesin), kvarts, hornblände och biotit. Mikroklin (pertitisk) förekommer i underordnad mängd. Båda fältspaterna bildar även större, xenoblastiska korn. Accessorier är titanit, apatit, epidot, ortit och opakmineral.

Plagioklasen har sammansättningen 34—37 % An, men i de större kornen



TH. LUNDQVIST 1957.

Fig. 11. Band i grå urgranit av en något mörkare granittyp. Sydöstra Riddarskäret.
A band in the grey gneiss-granite of a somewhat darker type of granite. SE Riddarskäret.

ligger An-halten högre: 42—45 %. I synnerhet de senare är ofta zonerade. Sericitomvandlingen blir kraftigare i kärnpartierna på dessa korn.

Runt de större mikroklinerna förekommer ibland myrmekitbildning.

Hornbländet visar den för vanligt hornblände normala pleokroismen: γ = blågrön, β = grön, α = ljust gulbrun. Absorptionen är stark, enligt $\gamma \geq \beta > \alpha$. $2V_\alpha$ ung. 45°, $c \wedge \gamma = 15°$, dubbelbrytning = 0.017. Poikiloblastiska texturer förekommer, med inneslutningar av huvudsakligen kvarts och accessorier i hornbländet.

Biotiten uppträder ofta i sammanväxning med hornblände. Klorit har ibland utbildats som omvandling av biotit.

Epidoten synes ha bildats ur plagioklas. Ortitkärnor är vanliga.

Basisk urgranit

Basisk urgranit förekommer i de amfibolitbreccior, som är vanliga på sydöstra Riddarskäret. Den kan därför antas ha uppkommit genom assimilation av material ur de basiska brottstyckena. Övergångar existerar till den normala grå graniten. Strukturen är i dessa mörkare urgraniter ibland massformig.

Halten av mörka mineral är högre än i den normala grå graniten. Mikroklin saknas, varför den basiska urgraniten är att beteckna som en kvartsdiorit.

Vidare saknas titanit. Titan ingår i stället i den mörkare graniten i ilmenit, vilken här är rikligare företrädd än i de surare granittyperna.

Plagioklas förekommer liksom i den normala grå graniten även som större, zonerade, xenoblastiska strökorn med samma eller något högre An-halt jämfört med i övriga plagioklaser. An-halten i de förra har uppmätts till 52—59 % An, i de senare till 52—56 % An. Skillnaden mellan de zonerade plagioklasernas kärnor och randzoner uppgår maximalt till ungefär 5—10 % An men är svår att bestämma exakt på grund av sericitomvandling och undulös utsläckning. Som inneslutningar i de större plagioklaserna påträffas kvarts, mindre plagioklaskorn, hornblände, biotit och accessorier. Biotit och kvarts utfyller sprickor i de större plagioklaserna.

Även hornbländet bildar större, oftast rundade korn med inneslutningar av kvarts, biotit och accessorier. Parallellorienteringen av c-axlarna är svagt utbildad. Pleokroismen är densamma som i den normala graniten, men $2V_\alpha$ är större än i denna: 53°—56°. $c \wedge \gamma = 14°—16°$, dubbelbrytningen = 0.017—0.019. För hornbländet med $2V_\alpha = 53°$ är vidare $n_\alpha = 1.674$, $n_\gamma = 1.691$.

Biotiten visar ofta prehnitomvandling. Brytningindex (n_γ) för snitt parallella med spaltytorna bestämdes i ett prov till 1.639.

Som tunn sprickfyllnad uppträder ibland prehnit.

INNESLUTNINGAR OCH INHOMOGENITETER I URGRANITEN

Amfibolitbrottstycken

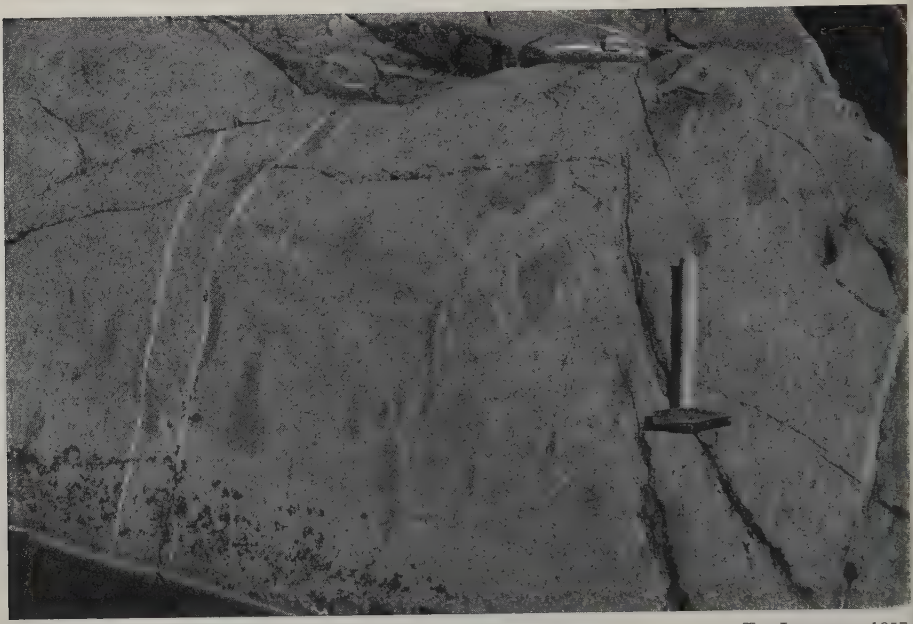
Brottstyckena, som utgöres av finkorniga, svarta amfiboliter, är av två typer, dels mer eller mindre starkt utdragna bitar, som ligger med längdaxlarna orienterade i granitens skiffrighetsriktning, dels större, kantiga, som ibland saknar utpräglad orientering. De förra förekommer allmänt spridda i den normala grå graniten, de senare endast i de breccior, som bildas av den mera basiska granittypen. Någon bandning har ej iakttagits i brottstyckena.

De mindre, avlånga brottstyckena är c:a 0.5—10 cm breda och c:a 3 cm—0.5 m långa och är särskilt i norra delen av området starkt utvalsade. I allmänhet är de väl avgränsade från graniten, men mer diffusa gränser mot den senare finns även. Fig. 12 visar amfibolitbrottstycken i en normal grå urgranit.

De dominerande mineralen är plagioklas (andesin-labrador) och hornblände samt kvarts och biotit. Accessorier är apatit, epidot, opakmineral och titanit.

Plagioklasen förekommer dels i en granoblastisk grundmassa, dels i större xenoblastiska korn, som ofta är zonarbyggda. De förra har sammansättningen 43—50 % An, de senare ung. 54 % An. I synnerhet de större plagioklaserna visar stark sericitomvandling.

Hornbländet har den normala pleokroismen: γ = blågrön, β = grön,



TH. LUNDQVIST 1957.

Fig. 12. Amfibolitbrottstycken i grå urgranit. Från området på plansch I b.
Amphibolite fragments in grey gneiss-granite. From the map area in plate I b.

α = ljust gulbrun. Absorptionen är stark enligt $\gamma \geq \beta > \alpha$. $2V_\alpha = 46°$, $c \wedge \gamma = 13°$, dubbelbrytning = 0.017.

Biotiten förekommer oftast intimt sammanvuxen med hornblände. Prehnitomvandling av biotiten är vanlig.

Bland accessorierna märks främst opakmineral och apatit. Titanit är sällsynt.

Epidot och sericit förekommer som omvandling av plagioklas. Epidotomvandlingen har ibland framgått efter sprickor i plagioklaserna.

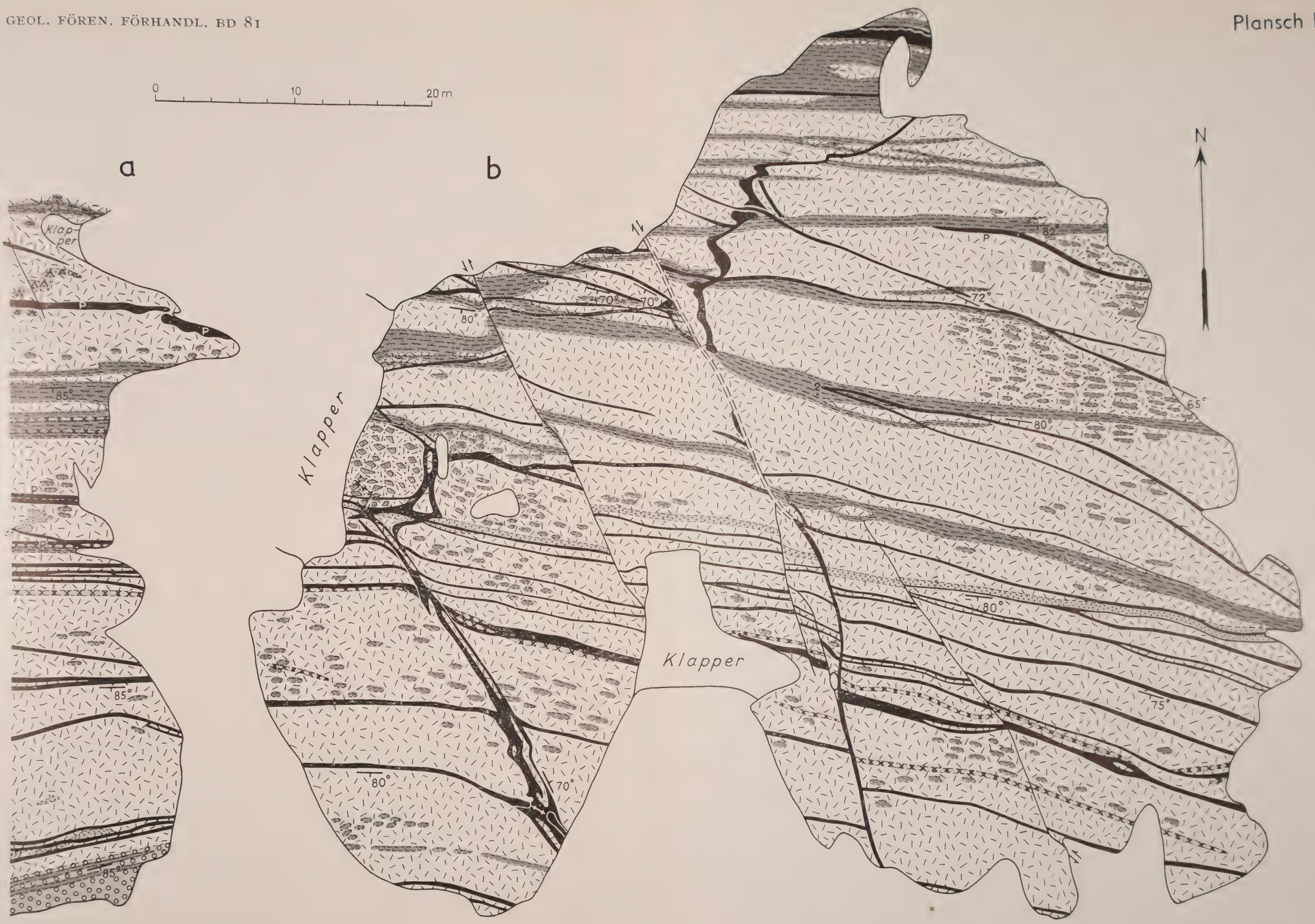
Stundom samlar sig amfibolitbrottstyckena till breccior med talrika brottstycken, som är större än de nyss nämnda (c:a 1—5 dm breda och 1—15 dm långa). Graniten i dessa breccior är som nämnts av den mera basiska typen.

Amfibolitbrottstyckena infogar sig även här i allmänhet i skiffrighetsriktningen. Där granitens skiffrighet är obetydlig blir dock brottstyckenas orientering föga utpräglad. Exempel på den senare typen visar fig. 13.

Plagioklas och hornblände utgör huvudmineral. Mer sparsamt förekommer kvarts och biotit, och accessoriskt apatit, epidot, opakmineral och zirkon.

Plagioklasen förekommer på samma sätt som i de mindre brottstyckena. De mindre, xenoblastiska kornen i grundmassan har sammansättningen 44—50 % An. De större plagioklaserna har troligen något högre An-halt, men kan ej närmare bestämmas på grund av stark sericitomvandling. Dessa större korn innesluter hornblände, biotit, kvarts och accessorier.

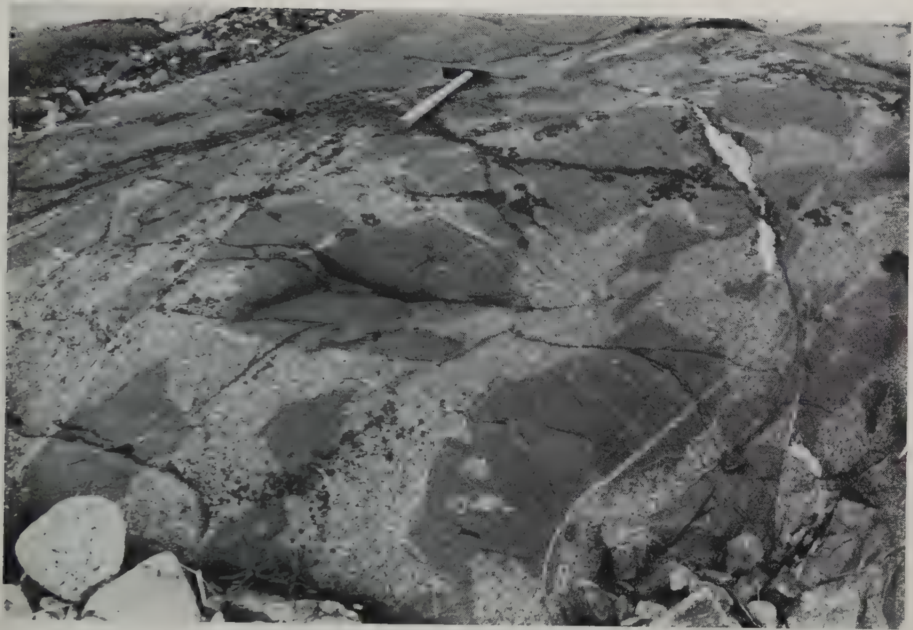
Hornbländena är mer eller mindre väl parallellorienterade. Poikiloblastiska texturer uppkommer, då hornblände innesluter kvarts, opakmineral m. m.



- ▤ Äldre, bandad amfibolit
  Older, banded amphibolite
- ▨ Äldre, ej bandad amfibolit
  Older amphibolite without banding
- Grå urgranit
  Grey gneiss-granite
- D:o med avlånga amfibolit-brottstycken
  Do. with elongated amphibolite fragments
- Basisk urgranit
  Quartz diorite
- D:o, breccierande amfibolit
  Do., brecciating amphibolite
- Bandad urgranit
  Banded gneiss-granite
- Röd aplit
  Red aplite
- Grå aplit
  Grey aplite
- D:o, porfyrisk
  Do., porphyritic
- Granitporfyr
  Granite porphyry
- Amfibolitgång
  Amphibolite dike
- P Porfyritisk amfibolitgång
  Porphyritic amphibolite dike
- Pegmatit
  Pegmatite
- Pegmatitisk kvarts
  Vein quartz
- Förkastning (pilarna anger den relativa rörelseriktningen)
  Fault (Arrows indicate the relative direction of movement)
- Zoner med stark förskiffring
  Zones with strong schistosity
- 70° Strykning och stupning
  Strike and dip

TH. LUNDQVIST del., M. EKMAN cop.

Områdets läge se fig. 6. ***The location see Fig. 6.***



TH. LUNDQVIST 1957.

Fig. 13. Basisk urgranit (kvartsdiorit), breccierande amfibolit. Upptill t. h. en kvartsfylld spricka. Från området på plansch I b.
Quartz diorite brecciating amphibolite. To the upper right a quartz vein. From the map area in plate I b.

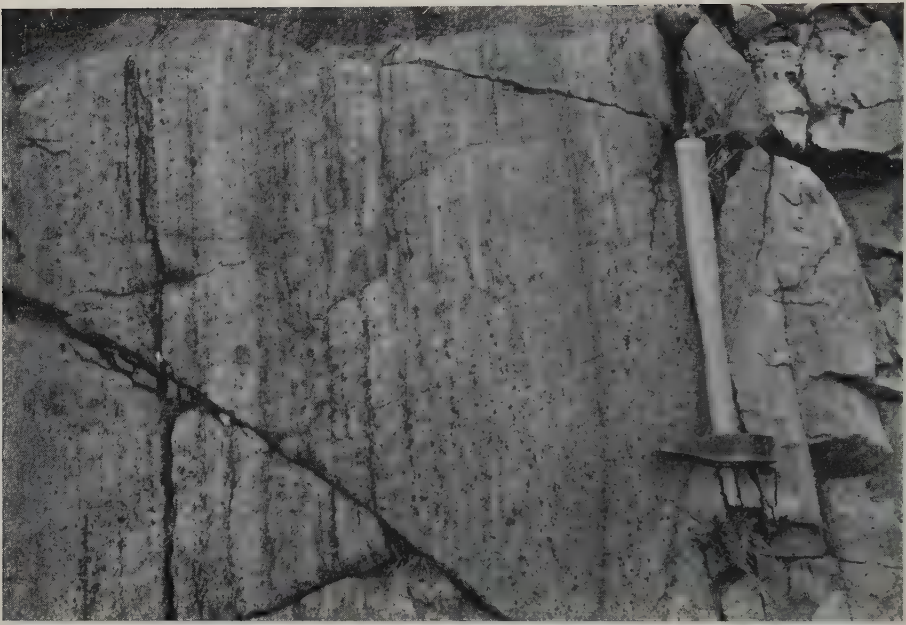
De optiska egenskaperna är följande. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun, absorption stark enligt $\gamma \geq \beta > \alpha$. $2V_\alpha = 57°—59°$, $c \wedge \gamma = 14°—16°$, dubbelbrytning 0.017—0.018.

Beträffande biotit och accessorier gäller vad som ovan sagts i beskrivningen av de mindre brottstyckena.

Bandad urgranit

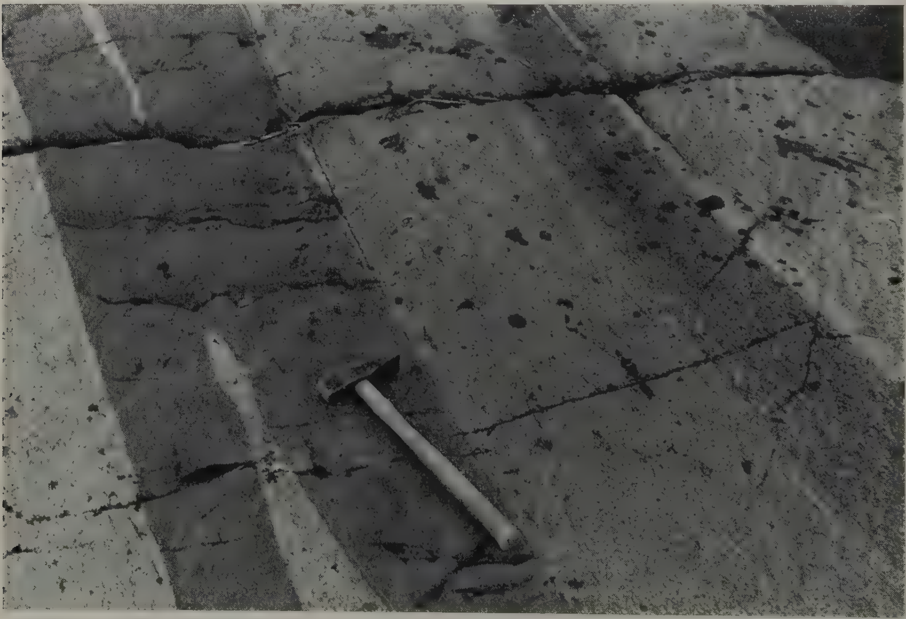
En bandning i graniten framträder understundom, i det att finkorniga, ljusgrå band alternerar med medelkorniga band av grå gnejsgranit (fig. 14). Bandens bredd är vanligen några få cm. Även starkt utdragna amfibolitbrottstycken förekommer i dylika bandade partier. Dessa påträffas, som framgår av kartorna, huvudsakligen på mellersta och norra Riddarskäret. En något avvikande typ förekommer sällsynt på norra Fogdö (fig. 15). Som framgår av bilden är det här fråga om medelkorniga, mörkare band i granitens skiffrighetsriktning.

Mikroskopisk undersökning visar, att de finkorniga leden har ungefär samma mineralsammansättning som de medelkorniga. Texturen är i bägge fallen granoblastisk (fig. 16). Kvarts och plagioklas (andesin) dominerar, med underordnade mängder hornblände och biotit. Mikroklin har däremot ej påträffats i de undersökta proven. Accessoriskt förekommer titanit, opakmineral, apatit, zirkon, rutil och epidot, den senare dock ibland i riklig mängd.



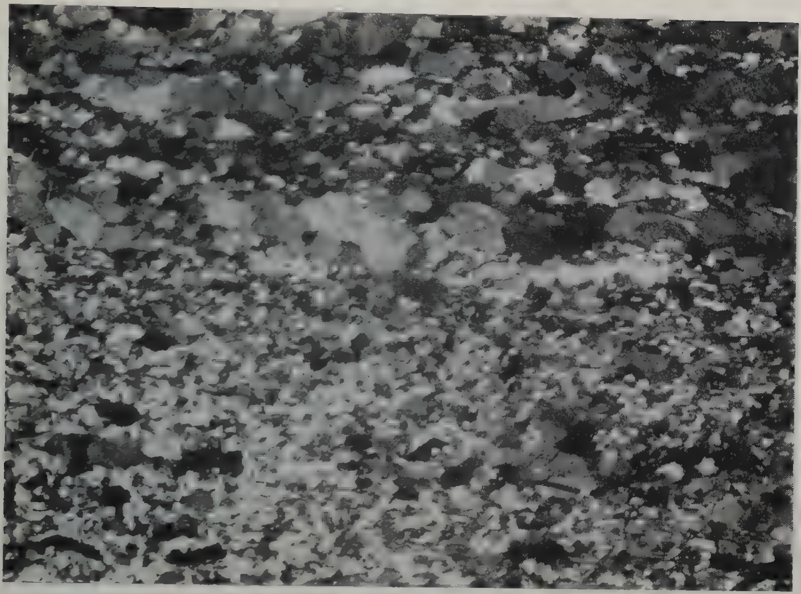
Th. Lundqvist 1957.

Fig. 14. Bandning i grå urgranit. T. h. en kvartsrik grå aplitgång. Från kartområdet i fig. 3.
Banding in grey gneiss-granite. To the right, a quartz rich grey aplite dike. From the map area in fig. 3.



Th. Lundqvist 1957.

Fig. 15. Från vänster till höger: Grå urgranit, amfibolitgång med urgranitskivor, grå urgranit, mörk bandning i urgranit, smal grå aplitgång, grå urgranit. Graniten t. v. är något ljusare än t. h. Från norra Fogdö.
From left to right: Grey gneiss-granite, amphibolite dike with lenses of gneiss-granite, dark banding in gneiss-granite, small grey aplite dike, grey gneiss-granite. The granite on the left is somewhat lighter than the granite on the right. From N Fogdö.



Th. Lundqvist 1958.

Fig. 16. Omväxlande finkorniga och medelkorniga band ur bandad grå urgranit. + nic. 9×.
Alternating fine-grained and medium-grained bands in the banded grey gneiss-granite. + nic. 9×.

Kvartsen är starkt undulös och bildar ofta större korn, utdragna i skiffrighetsriktningen.

Plagioklasen är en andesin med 36—41 % An. Den visar ofta kraftig epidot-sericitomvandling.

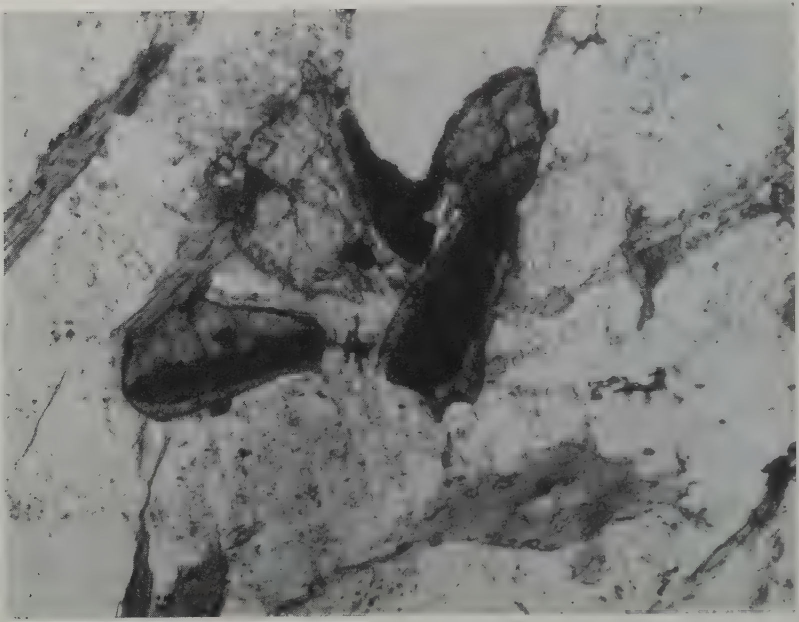
Två olika slag av hornbländen förefinnas, dels den i graniten normalt förekommande, starkt absorberande typen, dels en typ med svagare absorption. Det förra hornbländet har följande optiska data. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun. Absorption stark enl. $\gamma \geq \beta > \alpha$. $2V_\alpha$ ung. 45°, $c \wedge \gamma = 15°$, dubbelbrytning = 0.017. Det senare hornbländet företer samma pleokroism. Absorptionen är betydligt svagare ehuru fläckar med starkare absorption existerar. $2V_\alpha = 74°$, $c \wedge \gamma = 15°$, dubbelbrytning = 0.020. c-axlarna i hornbländena ligger i allmänhet orienterade i skiffrighetsplanen.

Biotiten är understundom prehnitomvandlad.

Titaniten tilldrar sig ett speciellt intresse. Den uppvisar en relativt stark pleokroism i brunt till färglöst. Den innehåller vidare ofta en kärna av rutil eller ilmenit (fig. 17).

Det vanligaste opakmineralet är svavelkis. Den förekommer ibland tillsammans med magnetit och har då troligen bildats sekundärt ur det senare. Som nämnts förekommer även ilmenit. Den bandade graniten företer sålunda vid jämförelse med normal urgranit en viss anriktning av mineral med tungmineralkaraktär. Detta kan möjligen antyda att sedimentärt material har ingått i graniten.

Zirkon förekommer sparsamt.



TH. LUNDQVIST 1958.

Fig. 17. Rutil (svart), omgiven av titanit. Ur bandad grå urgranit. 1 nic. 150×.
Rutile (black) surrounded by sphene in banded grey gneiss-granite. 1 nic. 150×.

Epidot är vanlig, ibland rikligt förekommande, dels som omvandlingsmineral ur plagioklas, dels som mer självständiga korn. Ortitkärnor är vanliga i epidoten.

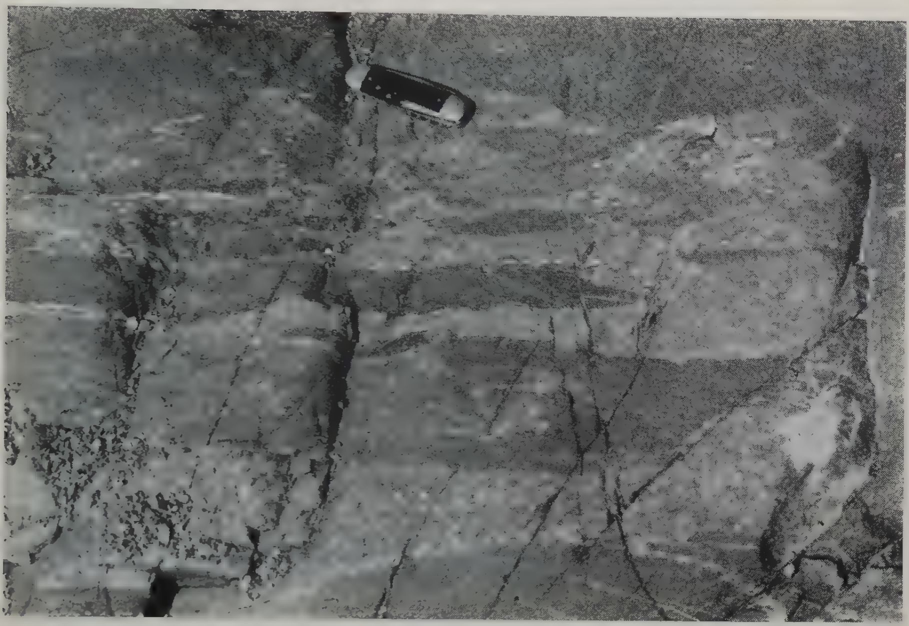
I detta sammanhang bör även påpekas, att graniten ibland innehåller epidotkörtlar med boudinagestruktur.

GÅNGBERGARTER

Röda och grå aplitgångar

Aplitgångarna genomsätter urgraniten konkordant med skiffrigheten. I sällsynta fall bildar de mer oregelbundna sliror i graniten. Bredden varierar från någon cm till ungefär 2 m. Gångarna avskäres av nedan beskrivna WNW-liga amfibolitgångar och står således i åldershänseende mellan dessa och urgraniten. De röda aplitgångarna är vanligen finkorniga, men till samma grupp bör också räknas en något grövre, fint medelkornig gång på södra delen av kartan i fig. 3. De grå aplitgångarna, som är vanligare än de röda, är även finkorniga, och visar stundom plagioklasporfyrisk utbildning. De genomsätter bl. a. amfibolitbrottstyckena i ovan beskrivna breccior, varigenom deras karaktär av gångar är bevisad. Övergångar mellan röda och grå apliter existerar.

Huvudmineralen i de röda apliterna är kvarts, plagioklas och mikroklin. I underordnad mängd uppträder biotit, och accessoriskt apatit, opakmineral och titanit. Som omvandlingsmineral uppträder epidot, sericit,klorit och prehnit.



TH. LUNDQVIST 1957.

Fig. 18. Granitporfyr breccierande amfibolit. Sydöstra Riddarskäret.
Granite porphyry brecciating amphibolite. SE Riddarskäret.

Plagioklasen utgöres av oligoklas eller andesin med An-halter från 24 till 32 %. Den är starkt sericitiserad, vilket försvårar exakta bestämningar av sammansättningen. Epidot har också bildats ur plagioklasen.

I ungefär samma mängd som plagioklas uppträder en understundom pertitisk mikroklin.

Biotiten är ofta omvandlad till klorit eller prehnit. Det senare gäller särskilt den grövre gången på kartan i fig. 3.

Huvudmineralen i de grå apliterna är kvarts och plagioklas med underordnad biotit. Ibland förekommer även mikroklin, vilket ger upphov till de nyssnämnda övergångarna till de röda, mikroklinrikare apliterna. Accessorier är titanit, zirkon, apatit, opakmineral och muskovit. Som omvandlingsmineral uppträder sericit och epidot (båda bildade ur plagioklas), klorit och prehnit (båda ur biotit).

Kvartshalten blir stundom mycket hög, exempelvis i den breda gången på södra delen av kartan i fig. 3.

Plagioklasens sammansättning varierar från 20—36 % An. Värdet på 20 % An gäller den nyssnämnda kvartsrika gången. An-halten i de plagioklasrikare gångarna uppgår vanligen till 31—36 %. De större, porfyriska strökornen är xenoblastiska, diffust zonerade och starkt sericitiserade. De har ungefär samma sammansättning som de mindre plagioklaserna — c:a 30 % An.

Biotiten visar stark klorit-prehnitomvandling.

Titanit förekommer sparsamt. I den kvartsrika gången innehåller den kärnor

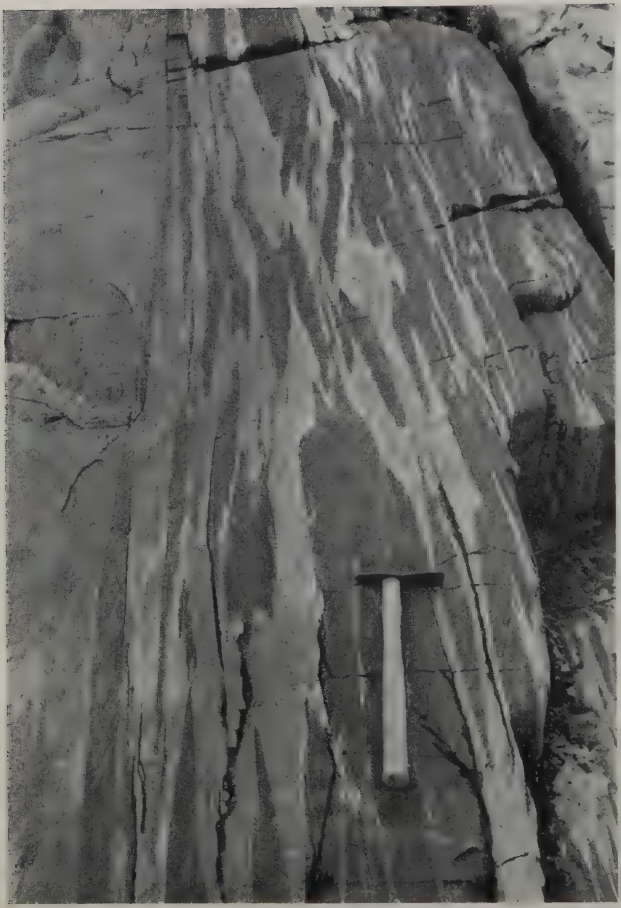


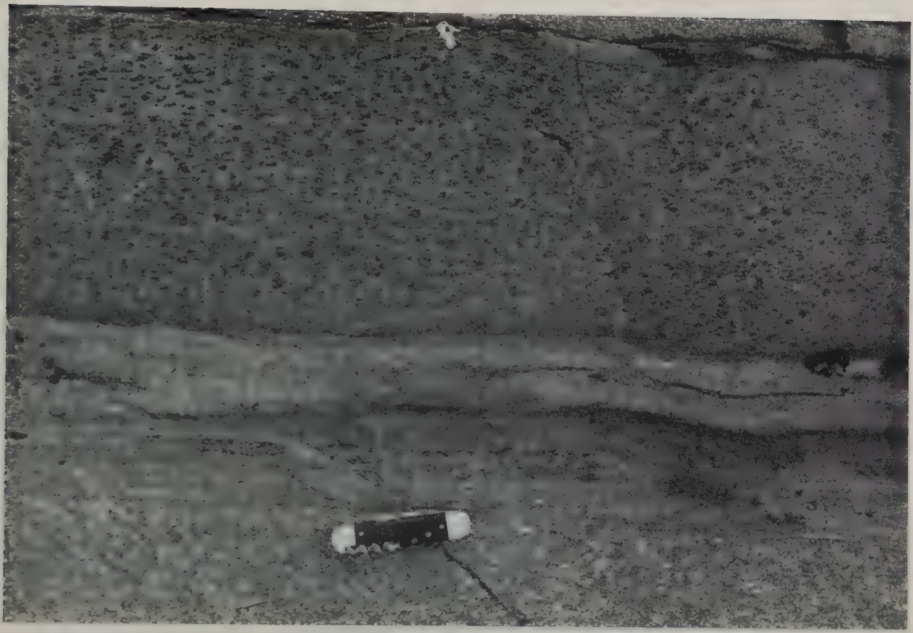
Fig. 19. Aplitmaterial breccierande amfibolit. Nordöstra Fogdö.
Aplitic material brecciating amphibolite. NE Fogdö.
Th. Lundqvist 1957.

av rutil. Som nämnts förekommer även zirkon. Det bör påpekas, att nämnda kvartsrika gång förekommer intill ovan beskrivna bandning i graniten. Den skymtar t. h. på fig. 14.

Granitporfyr

Som granitporfyr har betecknats två rödgrå-gråröda gångar av fint medelkornig granit, som för rikligt med plagioklasströkorn. Bredden är i observerade delar c:a 2 m. I den sydligaste av de båda gångarna (plansch I a) visar granitporfyren mot kontakterna finkornig, aplitisk utbildning, ibland med plagioklasströkorn. Detta förhållande antyder ett nära samband med de aplitiska gångarna.

Den sydligaste gången breccierar en amfibolit (fig. 18), vilken saknar bandning inom kartområdet. Längre åt väster uppträder dock diffusa mörka och ljusa partier. På grund av granitporfyrens nära samband med aplitgångarna och det förhållandet, att dessa är tydligt äldre än de WNW-liga amfibolitgångarna, har den breccierade amfiboliten hänförts till de äldsta amfiboliterna.



TH. LUNDQVIST 1957.

Fig. 20. Hornbländeporfyritisk konkordant amfibolitgång med ljusare randzon. Nedtill grå urgranit. Från kartområdet i fig. 2.
A concordant porphyritic amphibolite dike with a lighter marginal zone at the contact with the grey gneiss-granite. From the map area in fig. 2.

På nordöstra Fogdö påträffas breccior av liknande typ, med aplitiskt material innehållande brottstycken av amfibolit (fig. 19).

Granitporfyren består huvudsakligen av kvarts, plagioklas och mikroklin. Båda fältspaterna anträffas även som strökorn. Hornblände och biotit ingår mer underordnat. Accessoriskt förekommer opakmineral, apatit, titanit och zirkon. Som omvandlingsmineral uppträder epidot (med ortit), sericit (båda bildade ur plagioklas), klorit och prehnit (båda ur biotit).

Plagioklasen dominerar något över mikroklin. Sammansättningen är 29—38 % An. De större, porfyriska plagioklaserna har därvid ungefär samma sammansättning som de övriga.

Mikroklinen är ibland pertitisk. Längs kanterna på de större, xenoblastiska kornen har myrmekit utbildats.

Hornblände förekommer endast i den sydligaste gången. Pleokroismen är den normala: γ = blågrön, β = grön, α = ljust gulbrun. Absorptionen är stark. Absorptionsformel: $\gamma \geq \beta > \alpha$. $2V_\alpha$ är låg (ung. 45°), liksom dubbelbrytningen.

Biotit förekommer som parallellorienterade korn, till stor del prehnitkloritomvandlade.

Titaniten uppvisar relativt stark pleokroism i brunt till färglöst. Den är betydligt vanligare än zirkon.

Amfibolitgångar i N80° W (konkordanta)

De konkordant med granitens skiffrighet liggande amfibolitgångarna utgör ett markant inslag i berggrunden. Stupningen är ungefär 80° mot SSW. Bredden varierar från någon cm till c:a 1 m. Av utrymmesskäl har ej de smalaste gångarna kunnat medtagas vid karteringen.

Dessa gångar varierar från täta, grönggrå-grå, till svarta, något grövre typer. Stundom är färgen mycket ljust grå. Hornbländeporfyritiska gångar är vanliga (fig. 20).

De konkordanta amfibolitgångarna genomsätter ovan beskrivna apliter, men avskäres i sin tur av gångar med NNW-lig strykning. Vidare innehåller de (liksom de bandade amfiboliterna) urgranitskivor med boudinagestruktur.

Mineralogiskt uppvisar de konkordanta amfibolitgångarna samma variationer som de bandade amfiboliterna. De kan således ej på mineralogiska grunder skiljas från de senare, och uppträdandet i fält är därför den enda skiljaktigheten mellan de båda amfibolittyperna.

Plagioklas och hornblände dominerar sålunda, med kvarts och biotit i mer underordnad mängd. Accessorier är apatit, opakmineral, titanit och zirkon. Som omvandlingsmineral uppträder huvudsakligen sericit, epidot, klorit och prehnit.

Plagioklasen bildar xenoblastiska korn, mer sällan av strökornskaraktär. Dessa senare har sericitomvandlats så starkt, att det ej varit möjligt att bestämma sammansättningen. Plagioklassammansättningen varierar från 40—52 % An. Någon tydlig skillnad i plagioklasernas sammansättning i gångar rikare och fattigare på hornblände föreligger ej.

Plagioklaserna är alltid mer eller mindre starkt epidot-sericitomvandlade.

Beträffande hornbländets orientering, kristallform m. m. gäller vad som sagts ovan under »Bandade amfiboliter» (sid. 108). Hornbländet bildar även aggregat av större korn, vilket ger amfiboliten porfyritisk karaktär. Dessa större korn har samma optiska egenskaper som de övriga. Poikiloblastiska texturer är vanliga, i synnerhet i de större hornbländena. Inneslutningarna består huvudsakligen av kvarts och accessorier.

Hornbländets optiska egenskaper företer följande variationer. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun. Absorption enl. $\gamma \geq \beta > \alpha$ (se nedan), $2V_\alpha = 44°—74°$, $c \wedge \gamma = 13°—18°$, dubbelbrytning = 0.016—0.022. Absorptionen är i allmänhet starkast i hornbländen med små axelvinklar. $c \wedge \gamma$ och dubbelbrytningen ökar båda något, då $2V_\alpha$ ökar. Ljusbrytningsbestämningar visar, att brytningsindex är högst i hornbländen karakteriserade av små axelvinklar. (Se vidare nedan under »Allmän översikt av hornbländets och biotitens egenskaper och sammansättning».)

Kvartsen är undulös, xenoblastisk.

Biotit uppträder dels som självständiga korn, dels i intim sammanväxning med hornblände. Den är i allmänhet väl reglerad med spaltytorna parallella med skiffrigheten. Undantagsvis saknas biotit helt. Ljusbrytningsbestämningar ha utförts på biotiten i snitt parallella med spaltytorna i en del av de prov,

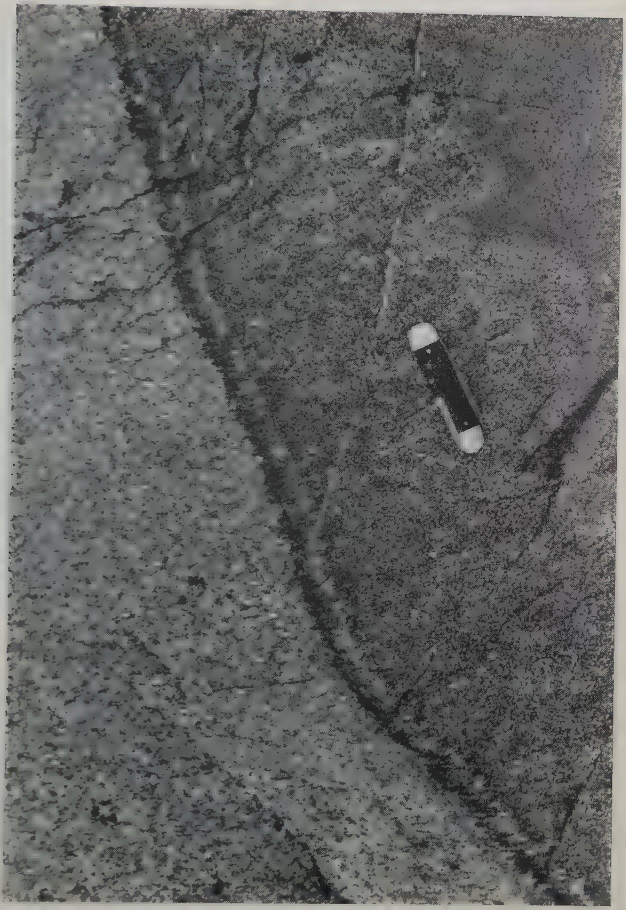


Fig. 21. Salbandsstruktur vid kontakten mellan grå urgranit och NNW-lig amfibolitgång. Norra Fogdö.
Zonal structure at the contact between the grey gneiss-granite and an amphibolite dike striking NNW. From N Fogdö.
TH. LUNDQVIST 1957.

där bestämning gjorts av hornbländets ljusbrytning. Tendensen är densamma som i de bandade amfiboliterna: då n_α för hornblände avtar, minskar även n_γ för biotit. (Se nedan.)

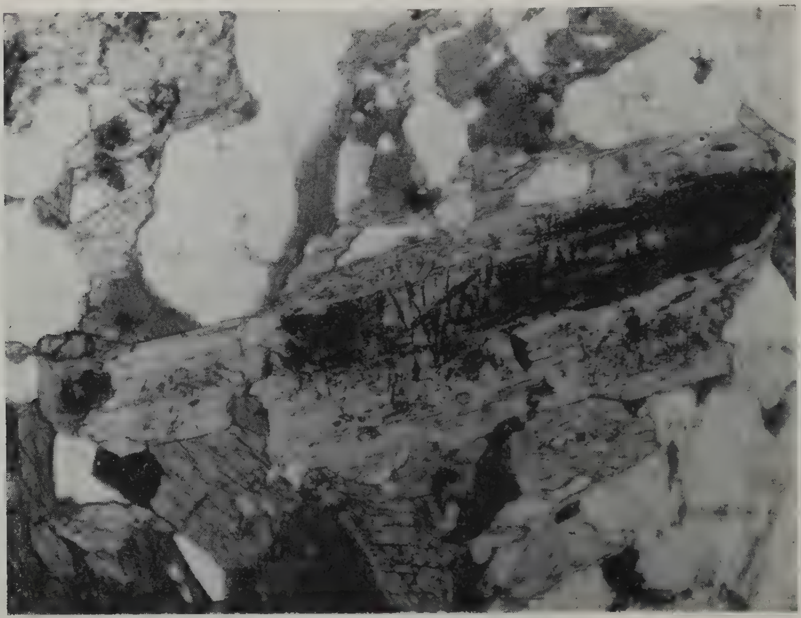
Biotiten är ofta omvandlad till prehnit, mera sällan till klorit.

I en grövre, fint medelkornig grönstensgång (plansch I b, norra spetsen) innehåller titaniten ilmenitkärnor. Denna gång utmärkes f. ö. av en synnerligen stark prehnitomvandling av biotiten.

Den ljusare randzonen till den hornbländeporfyritiska gången på mellersta delen av kartan i fig. 2 (se fig. 20) innehåller proportionsvis mera plagioklas än själva gången. Detta mineral är starkt sericitomvandlat. Även biotiten är kraftigt omvandlad till prehnit. Här har även påträffats titanit med ilmenitkärnor.

NNW-liga amfibolitgångar

De NNW-liga amfibolitgångarna är mindre rikligt företrädda än de föregående. De genomsätter förutom graniten även leptit, bandade amfiboliter,



TH. LUNDQVIST 1958.

Fig. 22. Hornblände med fläckar av ilmenit i kärnpartiet. Ur NNW-lig amfibolitgång. 1 nic. 55 ×.
Hornblende spotted by ilmenite in the centre of the grain. From an amphibolite dike strikingNNW. 1 nic. 55 ×.

apliter, granitporfyr och konkordanta amfibolitgångar. Den östra gången på plansch I b innehåller brottstycken av en hornbländerik gabbro eller diorit. De NNW-liga amfiboliterna stryker i allmänhet i N 10°—20°W och stupar brant eller lodrätt. Bredden varierar från några cm till c:a 2 m. De är ofta kraftigt deformerade och avslitna genom glidningar parallellt med granitens skiffrighet. (Se t. ex. fig. 5.) De tunnar ofta ut och övergår i kraftigt förskiffrade zoner i granit m. m. Dessa amfiboliter är finkorniga till täta, och färgen är grönsvart till svart. En grövre, fint medelkornig NNW-lig amfibolitgång anstår på norra Fogdö. Den visar vackra salbandsstrukturer (fig. 21). Hornbländeoch plagioklasporfyritiska typer förekommer sparsamt.

Texturen visar, att en kraftig nedkrossning av de ingående mineralen ofta skett.

Hornblände är det dominerande mineralet. Plagioklas förekommer i varierande mängd, men saknas ibland helt. Den är oftast synnerligen starkt omvandlad till sericit och epidot. Biotit är vanlig, men kvarts förekommer sällan.

Accessorier är titanit, opakmineral, apatit och zirkon. Tunna sprickfyllnader av prehnit är vanliga.

Hornbländet visar endast små variationer i optiskt hänseende, jämfört med tidigare beskrivna amfiboliter. Det förekommer någon gång som anhopningar av större korn. Dessa har samma optiska egenskaper som de övriga hornbländena. Beträffande orientering och kornbegränsning gäller detsamma som för de bandade amfiboliterna. I den nyssnämnda fint medelkorniga amfiboliten på norra Fogdö innehåller kärnpartierna fläckar av finfördelad ilmenit, se fig. 22. De optiska egenskaperna är följande. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun—färglös. Absorption svag—medelstark enligt $\gamma \geq \beta > \alpha$. $2V_\alpha = 71°—79°$, $c \wedge \gamma = 15°—16°$, dubbelbrytning = 0.017—0.021. För ett hornblände med $2V_\alpha = 77°$ bestämdes $n_\alpha = 1.640$, $n_\gamma = 1.661$.

Plagioklassammansättningen är 43—52 % An i de prov, där fältspaterna är någorlunda väl bevarade.

Biotit förekommer i sammanväxning med hornblände. Den visar ibland prehnitomvandling. Undantagsvis saknas biotit helt.

Kvarts förekommer endast accessoriskt i en del fall. Den är starkt undulös.

Bland accessorierna bör särskilt titanit framhållas. I den fint medelkorniga gången på norra Fogdö innehåller den ilmenitkärnor. Övriga accessorier är betydligt mer underordnade. Bland opakmineralen märks pyrit, kopparkis och magnetit.

Av omvandlingsmineralen dominerar epidot. Den förekommer ibland i betydande mängd och har troligen bildats ur plagioklas, ehuru denna omvandling ofta är så långt framskriden, att plagioklaserna praktiskt taget utplånats. Detsamma gäller sericitomvandlingen.

Amfibolitgångar i N70°W

Dessa WNW-liga amfibolitgångar representerar den yngsta amfibolitgenerationen inom området. Strykningsriktningen avviker endast obetydligt (i medeltal c:a 10°) från de konkordanta amfibolitgångarnas. I regel stupar de yngsta gångarna även något flackare (c:a 70° mot SSW). Att säkert särskilja mellan dessa bägge generationer i fält är på grund av de små differenserna i strykning och stupning ej möjligt. De yngsta gångarna kan dock med säkerhet identifieras, då de genomsätter NNW-liga gångar, så t. ex. på norra delen av kartan å plansch I b och på nordöstra Fogdö. Av alla iakttagelser i fält att döma är dock de yngsta gångarna sparsamt representerade.

Mäktigheten på dessa gångar är vanligen några få dm.

Hornblände och plagioklas dominerar, och mer underordnat förekommer kvarts och biotit. Accessorier är titanit, apatit, opakmineral och zirkon. Som omvandlingsmineral uppträder epidot och sericit, båda bildade ur plagioklas.

Hornbländet uppvisar följande optiska egenskaper. Pleokroism: γ = blågrön, β = grön, α = ljust gulbrun, absorption stark—medelstark enligt $\gamma \geq \beta > \alpha$. $2V_\alpha = 47°—53°$, $c \wedge \gamma = 13°—16°$, dubbelbrytning = 0.016—0.018.

Plagioklasen är en andesin med 39—44 % An. Den visar som i övriga amfiboliter alltid xenoblastisk kornbegränsning.

Kvarts förekommer som xenoblastiska, undulösa korn.

Titaniten innehåller ibland kärnor av ilmenit. Den är jämte opakmineralen den viktigaste bland accessorierna. Apatit och zirkon förekommer mer sparsamt.

Pegmatit

Den yngsta bergarten i området representeras av en röd, grov till medelkornig, mikroklinrik pegmatit, vilken förekommer på östra delen av mellersta

Riddarskäret (fig. 2) som en flackt stupande skiva, samt längre norrut (fig. 3) som en smal gång, strykande i N10°E. På den förra lokalen genomsätter den bl. a. en NNW-lig amfibolitgång. Slutligen förekommer här och var pegmatitiska kvartsgångar, varav säkerligen en del är att jämställa till tiden med den röda pegmatiten.

Förkastningar

Området genomdrages av förkastningar, i huvudsak med NNW-lig, men även med NE-lig strykning. De förra sammanhänger med de NNW-liga amfibolitgångarna, vilka utfyller en del av förkastningssprickorna. Vackra medsläpningsstrukturer har ofta utbildats (ex. plansch I b, norra delen). Den relativa förskjutningen i horisontalled uppgår till maximalt 2 à 3 m.

Vidare har kraftiga glidningar skett efter granitens skiffrighetsplan. Detta framgår av att de NNW-liga gångarna har förskjutits och avslitits (fig. 5, plansch I b, norra delen).

Allmän översikt av hornbländets och biotitens egenskaper och sammansättning

Ljusbrytningen (n_α) för hornblände, vilken bestämts med immersionsmetoden, har korrelerats med en serie värden på axelvinkeln, varierande från 44° till 77°. Härvid har såväl urgranit som bandade amfiboliter, WNW-liga (konkordanta) och NNW-liga amfibolitgångar representerats.

De erhållna resultaten (fig. 23) visar som tidigare nämnts, att då axelvinkeln ($2V_\alpha$) för hornblände ökar, avtar n_α. Vid $2V_\alpha = 60°—64°$ ändras n_α hastigare än på övriga delar av kurvan. Genom att fastställa de värden på Fe-halten och halten Al som substituerar Si (Al II), för vilka den bästa överensstämmelsen med de av SUNDIUS (1946) givna kurvorna erhålles, kan man erhålla en uppfattning om variationen i den kemiska sammansättningen:[1]

Då axelvinkeln ökar från 44° till 77° och n_α avtar från 1.679 till 1.640 (n_γ från 1.696 till 1.661), avtar halten ($Fe^{2+} + Fe^{3+} + Mn + Ti$) i procent av totala halten ($Mg + Fe^{2+} + Fe^{3+} + Mn + Ti$) från mellan 65 och 70 % till omkring och något under 50 %. Samtidigt avtar AlII — beräknad som 8.00 minus antalet Si-atomer på 24 (O, OH, F) — från ett värde > 1.4 till c:a 0.60. Enär spridningen kring de av SUNDIUS givna kurvorna är relativt stor, och överensstämmelsen med de av förf. erhållna värdena ibland dålig, måste ovan angivna kemiska sammansättningar betraktas som ungefärliga. Som framgått av de tidigare petrografiska beskrivningarna, förekommer hornbländena med högre halt av Fe och AlII i ljusare (plagioklas-kvartsrikare) bergarter.

I biotiten har brytningsindex (n_γ) bestämts för snitt parallella med spaltytorna. Som framgår av fig. 23 avtar n_γ parallellt med en minskning av n_α

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[1] Hornbländets n_γ har beräknats ur n_α med hjälp av värdet på dubbelbrytningen, vilken uppmätts med Berek-kompensator. Värdet på n_γ har sedan kontrollerats med immersionsmetoden.

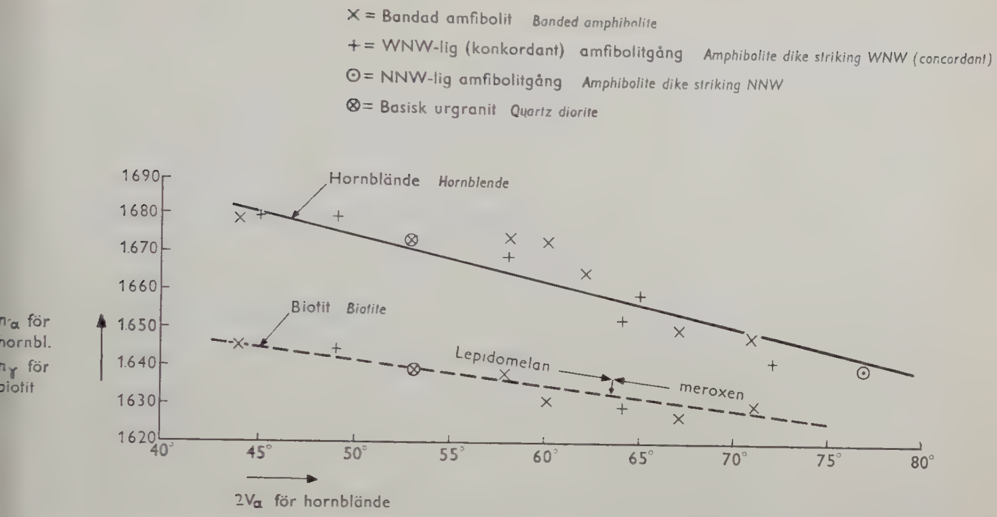

Fig. 23. Diagram visande variationerna i n_α för hornblände och n_γ för biotit med hornbländets axelvinkel ($2V_\alpha$). Värden ur samma prov har samma x-koordinat.
Diagram showing the variations of n_α of hornblende and n_γ of biotite in relation to the axial angles of the hornblende ($2V_\alpha$). Values from the same sample have an identical x-coordinate.

för hornblände, ehuru kurvan för biotit visar ett mindre brant förlopp. n_γ varierar från 1.645 till 1.630 då hornbländets n_α avtar från 1.679 till 1.649. Drar man enligt Tröger (efter Burckhardt 1943) gränsen mellan meroxen och den Fe-rikare lepidomelanen vid $n_\gamma = 1.633$, erhåller man de i fig. 23 angivna benämningarna på de olika biotiterna. Meroxenen förekommer således huvudsakligen i hornblände-biotitrikare bergarter. Färgen i snitt parallella med spaltytorna är vanligen brungrön. Biotiter, vilka är associerade med hornbländen med höga värden på $2V_\alpha$, uppvisar dock ofta en renare brun färg.

Sammanfattning

Av den presenterade beskrivningen framgår, att på Riddarskäret förekommer såväl sura suprakrustalbergarter (leptit), som basiska. De förra har skilts från apliterna (se sid. 104) främst på grund av analogierna med de på Singö uppträdande leptiterna. De bandade amfiboliterna har av flera skäl ansetts vara suprakrustalbergarter. De bladas ofta upp längs skiffrighetsplanen av urgraniten, som även sänder in sura ådror i dem. Vidare har en bandad amfibolit aldrig iakttagits avskära någon annan bergart i området. Bandningen är enligt författarens mening att tolka som en primär lagringsstruktur, men är troligtvis sekundärt skärpt genom tektoniska rörelser. På grund av att den homogena amfiboliten i granitbrecciorna också är äldre än urgraniten, vill man gärna förmoda, att dessa amfiboliter hör nära samman med de bandade amfibolittyperna. De senare bör uppfattas som basiska tuffiter och tuffer, möjligen med inslag av lavor, med i huvudsak dacitisk-andesitisk sammansättning. Kvartshalten är i många fall anmärkningsvärt hög, vilket kan innebära inblandning av normalt klastiskt sedimentmaterial.

De diffusa bandningen i urgraniten kan tänkas representera starkt assimilerade suprakrustalbergarter, vars ursprungliga karaktär dock ej är möjlig att fastställa.

Efter framträngandet av den grå urgraniten intruderade aplit och granitporfyr, vilka sannolikt utgör sura differentiat av urgranitmagman. Härefter uppkom sprickor i bergartskomplexen, vilka utfylldes av tre olika generationer grönstensgångar med strykningsriktningarna N80°W, NNW och N70°W resp. Dessa gångar uppvisar samma variationer i mineralsammansättningen som suprakrustalamfiboliterna. Som yngsta intrusioner i området följde sedan den röda pegmatiten.

Åldersförhållandena mellan bergarterna på Riddarskäret kan sammanfattas i följande schema:

(Yngst) Röd pegmatit
Amfibolitgångar i N70°W
Amfibolitgångar i NNW
Amfibolitgångar i N80°W
Granitporfyr, röd och grå aplit
Grå urgranit och basisk urgranit
(Äldst) Äldsta amfiboliter (delvis bandade), samt leptit.

Även om, såsom framgått av den givna beskrivningen, det ibland har stött på svårigheter att i varje enskilt fall karakterisera en bergart såsom tillhörande ett visst led i denna succession, visar dock fältiakttagelserna med full tydlighet, att samtliga led verkligen uppträder på Riddarskäret med omnejd.

Litteratur

(SGU = Sveriges Geologiska Undersökning, GFF = Geologiska Föreningens i Stockholm förhandlingar).

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Aktuella utvecklingslinjer inom svensk allmän kvartärgeologi

Av

TAGE NILSSON

Detta föredrag[1] avser att ge en inblick i den forskning, som bedrivits inom svensk allmän kvartärgeologi under det senaste decenniet, och framlägga vissa av de resultat som vunnits. Någon fullständig historik eftersträvas ej och kan för övrigt ej heller lämnas under den korta tid, som står mig till buds. Mycket mer än några glimtar kan det över huvud ej bli.

Det sista decenniet har sett en av den svenska kvartärgeologiens stormän, LENNART VON POST, försvinna. Han gick ur tiden på nyåret 1951. Åtta år tidigare hade en annan av svensk kvartärgeologis förgrundsgestalter, GERARD DE GEER, avträtt från skådebanan.

De initiativ dessa båda tagit och de impulser de gett sätta emellertid fortfarande i stor utsträckning sin prägel på svensk kvartärgeologi. Lervarvskronologi, glacialgeologi, utforskningen av nivåförändringarna, datering med hjälp av pollenanalys samt studiet av vegetationens historia och klimatutvecklingen under senkvartär tid bedrives fortfarande i stor utsträckning efter de linjer, som utformats eller utstakats av dem.

Efter hand har dock en hel del nya drag kommit in i bilden, som jag hoppas skall komma att framgå av det följande. Jag behöver för ögonblicket endast nämna datering med radioaktivt kol.

Sveriges geologiska undersöknings karteringsverksamhet

Sveriges geologiska undersöknings karteringsverksamhet har varit och är fortfarande av grundläggande betydelse för bl. a. svensk kvartärgeologi. Detaljkartläggning och bladutgivning i skala 1: 50 000 (kombinerade berggrunds- och jordartskartor, ser. Aa) har nått till norra delen av Mellansverige. Spridda blad i samma skala från sydligare delar av landet har också getts ut under de senare åren; delvis rör det sig om nya upplagor av äldre blad (i samma eller mindre skala). En ny serie ännu mera detaljerade s. k. agrogeologiska kartblad (ser. Ad) har startats i Skåne med utgivning av 9 stycken kartblad i stor skala, 1: 20 000, utarbetade av GUNNAR EKSTRÖM. I Nordsverige kan karteringen inte bedrivas med samma detaljering som i Mellan- och Sydsverige, om kartor skall kunna bli tillgängliga inom rimlig tid. Där har man övergått till utgivning av geologiska länskartor, översiktskartor i relativt liten skala, vilka publiceras i ser. Ca. De under det sista decenniet utgivna jordartskartorna av denna typ äro Kopparbergs län (1951, Gösta Lundqvist, skala 1: 250 000) och Värmlands län (1958, Jan Lundqvist, 1: 200 000). Under utgivning är en jordartskarta över Norrbotten (Erik Fromm). Utmärkande för de sista årens geologiska kartläggning är det arbete, som numera lägges ner på en noggrann karakterisering och uppdelning av jordarterna. Detta gäller i första hand Ekströms mycket detaljerade agrogeologiska kartblad, vilka särskilt äro avsedda att tjäna jordbrukets behov, men också övriga geologiska kartor. Framför allt moränjordarternas systematisering har blivit föremål för stort intresse (Gösta Lundqvist). Moränjordarterna spela ju en synnerligen viktig roll i vårt land, och en uppdelning av hithörande jordartstyper har stor betydelse för skogsbruket.

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[1] Föredrag hållet vid sjunde nordiska geologmötet i Stockholm den 4 juli 1958. Vid utredigeringen för tryckning ha vissa litteraturhänvisningar tillagts.

En översiktlig jordartskarta över hela landet har till detta möte utgivits av Gösta Lundqvist (i S. G. U. Ser. Ba, skala 1 000 000).[1]

Interglaciala avlagringar

Förekomsten av eventuella interglaciala avlagringar i Sverige har länge varit ett starkt omdiskuterat problem. Det vill synas, som om det sista årtiondets forskningar gett slutgiltigt och positivt besked i denna fråga, åtminstone för ett flertal nordsvenska fynd. Talrika lokaler med submoräna bildningar inom vissa delar av Norrland och angränsande delar av Svealand få i enlighet därmed anses vara av interglacial ålder. Det är längs två eller tre helt olika vägar, man kommit till detta resultat. Redan 1948 kunde Lindroth påvisa, att de fossila insekterna i de ifrågasatta interglaciala avlagringarna till stor del utgöras av arter, vars nutida utbredning gör det osannolikt, att de äro postglaciala. Under de allra sista åren ha en rad åldersbestämningar med kol-14-metoden utförts, som gå i samma riktning (Gösta Lundqvist 1955, 1957, Jan Lundqvist 1955, 1958, Östlund 1957). De ha gett följande värden:

Öje (Dalarna), submorän stock av gran: över 40 000 år (före nutiden)

Boliden (Västerbotten), submoräna växtrester: över 24 000 år

Bollnäs (Hälsingland), submorän gyttja: över 30 000 år

Pilgrimstad (Jämtland), fyndort för interglaciala mammutrester i primärt läge; submoräna växtrester: över 39 000 år

Vålbacken (Jämtland), submoräna växtlämningar: över 37 000 år

Fryksta (Värmland), granved i glacifluvial avlagring (= von Posts s. k. finiglaciala gran): över 30 000 år.

Samtliga förekomster ha alltså högre ålder än vad som kan bestämmas med mätmetoden.

På några ställen (Långsele, Bollnäs, Öje) ha dessutom pollenanalytiska undersökningar utförts. Vid Öje har Erdtman (Lundqvist 1955) bl. a. kunnat identifiera pollen av lärkträd *(Larix)*, som ju inte tillhör vår spontana postglaciala flora.

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[1] I den under utgivning varande Atlas över Sverige ingå ävenledes ett flertal kartor, belysande olika kvartärgeologiska fenomen.

Fynden av mammutrester ha efter hand ökat ganska betydligt. De härröra mest från Nordsverige och ha i regel anträffats i sekundärt läge i morän. Mammuten torde ursprungligen ha levat under interglacial tid i dessa nordliga trakter.

Glacialgeologi

Glacialgeologien måste ju av naturliga skäl intaga ett avsevärt utrymme inom svensk kvartärgeologi. Här är först att nämna den av ERIK LJUNGNER och hans skola (GUNNAR JOHNSSON, MARTIN MARKGREN, ÅKE MATTSSON) utarbetade och tillämpade hällanalysmetoden, en metod, som går ut på att med hjälp av isräfflor och andra spår efter isrörelser på hällar, deras hållbestämning och kvalitativa och kvantitativa värdering draga slutsatser, dels om isens beskaffenhet och växlande rörelseriktningar, dels om isrörelsernas kronologi och varaktighet. Genom hällanalys i de svenska fjälltrakterna trodde sig LJUNGNER bl. a. kunna konstatera, att den sista nedisningen sönderföll i två stadier, en äldre s. k. primnedisning och ett yngre huvudskede, då isen hade väsentligt större utbredning än under det första skedet. Båda stadierna skulle ha börjat som montannedisning i fjälltrakterna med isdelaren belägen väster om fjällkammen, varefter isdelaren försköts österut, så att den småningom kom att ligga öster om fjällen; detta skulle ha varit mest utpräglat under det yngre skedet. Dessutom ansåg sig LJUNGNER kunna konstatera komplicerade vridningar av isrörelsens riktning, orsakade av förskjutningar av iskulminationerna. LJUNGNERS eget arbete med denna teori avbröts genom hans för tidiga död (1954). Andra forskare, såsom G. LUNDQVIST och HOLDAR, ha ställt sig skeptiska mot möjligheterna att med utgångspunkt från hällanalys draga så vittgående slutsatser, som LJUNGNER gjort.

GUNNAR WENNBERG (1949) har kommit en del oro åstad genom sina omtolkningar av vissa glacialgeologiska förhållanden. Utgående från teoretiska överväganden med hänsyn till isens dynamik och med tillämpning i första hand på förhållandena i Skåne fann WENNBERG det omöjligt att acceptera den rådande åsikten, att en baltisk isström trängt in över bl. a. delar av Skåne, efter det att en tidigare s. k. nordostis under en interstadial tid smält bort. WENNBERG ansåg, att båda isarna voro samtidiga och hängde ihop med varandra, bildande en sammanhängande iskaka, inom vilken ursprungligen en nordöstlig isriktning dominerade. Efter hand som denna dog bort, skulle enligt WENNBERG genom differentialrörelse en baltisk strömningsriktning ha utbildats inom en del av iskakan. Som en konsekvens av sin uppfattning tvingades WENNBERG att omvärdera ett stort antal förhållanden. Han måste sålunda i många fall tillgripa teorien om subglacial sedimentation för att förklara förekomsten av finkorniga sediment under och mellan moränbildningar. Särskilt denna teori har mött kraftig kritik.[1] Vad förhållandena i Skåne beträffar — WENNBERG har också försökt tillämpa sina metoder på andra delar av Skandinavien — ha de allra senaste årens undersökningar (GUNNAR JOHNSson 1956, 1958; Hans Möller mskr.; Kaj Nilsson mskr.) visat, att någon verklig interstadialtid mellan nordostis och baltisk is ej funnits. Medan Wennbergs åsikt på denna punkt alltså styrkes, ge de nya undersökningarna emellertid i övrigt vid handen, att den baltiska isen i varje fall inom stora delar av Sydvästskåne måste ha ryckt fram över isfritt land. Tvånget att antaga mera omfattande subglacial sedimentation faller därmed för Skånes vidkommande bort.

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[1] Se diskussionen i Geologiska Föreningens i Stockholm Förhandlingar, Bd 73, 1951, pp. 316—318, 328—335.

Gösta Lundqvist (1948, 1949) har upptagit och vidare utvecklat metoden att genom studiet av de långsträckta stenarnas orientering i olika jordarter fastställa avlagringsriktning och jordartstyp, en metod som visat sig vara mycket fruktbar och använts av flera olika forskare för skilda kvartärgeologiska ändamål.

Bl. a. har Gunnar Hoppe (1952, 1957 etc.) tillämpat densamma vid sina betydelsefulla studier av de småkulliga moränlandskapens uppkomst. På ett övertygande sätt har han visat, att subglacial flytning av bottenmoränmaterial — alltså ej ytmorän som tidigare ofta antagits — spelat en stor roll i sammanhanget. Genom isens tryck har dylikt av smältvatten genomdränkt moränmaterial pressats in i subglaciala hålrum (smältvattensurgröpningar o. d.) och sprickor i isen. Denna behöver f. ö. ej ha varit helt död — den ofta använda benämningen dödismorän skulle alltså ej alltid vara helt adekvat. Stora delar av Norrland över MG upptagas av dylika småkulliga moränlandskap, liksom också vissa supraakvatiskt bildade moränområden i Sydsverige. Årsmoränliknande bildningar i dessa områden ha enligt Hoppe ingenting med årsmoräner att göra.

Ett annat viktigt resultat av Hoppes och hans elevers forskningar berör isavsmältningen i Nordsverige. Enligt den allmänna uppfattningen skulle isen överallt i Norrland sist ha smält bort från isdelaren öster om fjällkedjan, där isen var mäktigast. Mellan dessa dödisrester och passpunkterna i fjällen skulle stora issjöar ha uppdämts. Vad nordligaste Norrland anbelangar, har emellertid C.-G. Holdar, en elev till Hoppe, i ett nyutkommet arbete (1957) klarlagt, att en Torneissjö, som tidigare av Sjögren antagits ha förekommit i Torneträskområdet i deglaciationens slutstadium, aldrig har förekommit. Isen smälte där sist bort från fjällen, och något tillfälle till issjöuppdämning i stor skala gavs ej.

Hoppe antar — i likhet med Ljungner — en mycket omfattande montanglaciation i den sista nedisningens initialskede. Ett stort antal lågt liggande glaciärnischer, vilka måste ha utbildats före sista isens maximum, tyder därpå. Holdar talar om montanglaciation både vid början och slutet av nedisningen och om en s. k. storis (med isdelare öster om fjällen) vid dess maximistånd.

Förutom i fjälltrakterna ha vitt utbredda issjöar antagits också för avsmältningstiden i Sydsverige (Erik Nilsson). Redan 1942 frågade sig emellertid Gösta Lundqvist, var issjöarnas sediment fanns. Han framhöll, att dödisar måste ha upptagit större delen av de antagna issjöarnas djupare delar, så att på sin höjd endast randområden mellan isarna och högre liggande områden varit upptagna av öppet vatten. Sediment kunde därför endast komma till avsättning i lokala smala stråk. Denna uppfattning synes ha bekräftats bl. a. av GILLBERGS undersökningar i västra Sydsverige (1956).

Av mycket stor betydelse, bl. a. för vår kännedom om klimatet under senglacial tid, är upptäckten av iskilar i Skåne. Iskilar voro tidigare på nordiskt område endast kända i Danmark (framför allt på Jylland väster om de östjylländska ändmoränerna). De första uppgifterna om iskilar och andra frostfenomen (frostveckningar) i Skåne lämnades av GUNNAR JOHNSSON (1956). Medan de fenomen, som tolkats som frostveckningar, mött invändningar från vissa håll, ha iskilarna blivit allmänt godtagna, även av utländsk expertis (WOLDSTEDT, BÜDEL). Iskilarna utgöras av frostsprickor, som successivt vidgats genom upprepad frysning av smältvatten och därigenom fått formen av kilar med nedåt avsmalnande spets. De ha fyllts med yngre sediment, som sjunkit ner i kilen, när isen i densamma smält bort. De enklaste typerna av iskilar ha en jämnbred streckform och ha troligen kunnat bildas genom frost under loppet av ett enda år. För bildning av typiska, breda iskilar kräves en betydligt längre tidrymd. En förutsättning för bildningen av sådana iskilar synes vara förekomsten av evig tjäle. De hittills beskrivna skånska iskilarna äro funna i trakten av Landskrona (Saxtorp, strandklintarna vid Glumslöv) och på ön Ven. Iskilarna vid Saxtorp äro utbildade i glacifluvialt grus. De börja 1/2—1 m under ytan och ha där en bredd, som kan uppgå till 1/2 m; de bäst utvecklade gå ned till 4 m djup. — Iskilar av olika ålder ha anträffats. De yngsta äro yngre än den baltiska isströmmen. Äldre iskilar finnas enligt nyare undersökningar av JOHNSSON (1958), dels mellan NO-morän och baltisk morän, dels under NO-morän. Fynden av iskilar äro av vikt inte bara genom den klimatologiska innebörd de ha utan också genom att de ange isfritt, ej vattentäckt område vid tiden för iskilsbildningen.

Lervarvskronologi

Lervarvskronologien är ju en forskningsgren med vissa traditioner här i Sverige. GERARD DE GEERS arbete har fortsatts av fru EBBA HULT DE GEER, som särskilt i ett par arbeten av år 1954 och 1957 gett översikter och synpunkter på Skandinaviens geokronologi. F. ö. karakteriseras detta forskningsfält av att man allt mer börjat företaga kontrolluppmätningar och nymätningar av lervarvsserier inom vissa kritiska områden. Hittills ha endast smärre justeringar blivit resultatet. Sålunda ha BORELL och OFFERBERG (1955) i Indalsälvens dalgång funnit, att årtalet för den centraljämtska issjöns tappning och bipartitionen av inlandsisen, alltså DE GEERS 0-år, blivit felkonnekterat av DE GEER och i verkligheten inföll 84 år före det i praktiken tillämpade 0-året. Om man vill fasthålla vid DE GEERS definition av 0-året som lika med året för bipartitionen, skulle alltså 0-året behöva förskjutas nämnda antal år tillbaka i tidskalan. — Foliekärnborret[1] har vidare möjliggjort, att man numera lättare än förut kan få fullständiga profiler genom varvig lera ända ned till bottenvarvet. Lervarvsmätningar med foliekärnborr ha utförts eller äro i gång på flera ställen i vårt land (Erik Nilsson, Björn Järnefors).

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[1] Beträffande detta borr se KJELLMAN, KALLSTENIUS & WAGNER (1950).

Nivåförändringarna

Frågan om nivåförändringarna är ett klassiskt svenskt forskningsobjekt. Som framgår av det föregående, råda ej sällan stridiga meningar om kvartärgeologiska problemställningar. Frågan om nivåförändringarna äro i detta hänseende alldeles särskilt kontroversiell. Här stå delvis diametralt motsatta meningar mot varandra, och ännu synas vi vara ett gott stycke från målet att överbrygga motsättningarna. Jag får därför i stor utsträckning inskränka mig till att ställa åsikt mot åsikt.

Den gräns till vilken havet och de stora baltiska vattnen nått upp, MG — det är uttytt den »maximala» gränsen eller högsta kustlinjen, är givetvis viktig att fastställa. Här synes det vara klarlagt, att många bestämningar synas vara alldeles för höga, tydligen beroende på svårigheten att skilja MG från lokala, högre belägna issjöstrandlinjer o. d. Hänsynstagande till förekomsten av s. k. dödisterräng och glacifluviala skvalrännor, som ej förekomma nedanför MG, ha gett mera restriktiva värden.

Ett väldigt observationsmaterial för belysning av nivåförändringarna har insamlats i västra Sverige, särskilt i Viskadalen, av Lennart von Post och hans lärjungar. Detta senare område utvaldes av von Post som särskilt lämpligt för utredningen bl. a. beträffande den roll, som havets eustatiska stigning spelat för nivåförändringsförloppet. Det var tragiskt, att von Post, som hade alla trådarna i sin hand, aldrig hann med att fullständigt sammanställa resultaten av sin Viskaundersökning. En liten del av materialet har dock posthumt publicerats av Wenner.

Flertalet av de forskare, som ägnat sig åt nivåförändringsproblemet — jag kan förutom Lennart von Post (1947, 1948 och tidigare) nämna Gunnar Gillberg (1956; Västsverige) och Erik Nilsson (1953, 1958; Sydsverige) — har använt sig av metoden att lägga in sina strandlinjeobservationer i strandlinjediagram, antingen i distansdiagram eller s. k. relationsdiagram. Ett undantag utgör Sten Florin (1944—48), som i sitt undersökningsområde, Södermanland, anser sig ha funnit så olikformiga nivåförändringar inom närgränsande områden, att han ej kunnat tillämpa metoden med strandlinjediagram. Väsentligt olika slutsatser ha dragits av dessa diagram; jag kan dock här ej gå in på eventuella orsaker till åsiktsdivergenserna.

Å ena sidan ha von Post och Gillberg — liksom f. ö. också Florin ur sitt material, fast på andra grunder — läst ut mycket komplicerade strandförskjutningsförlopp under senkvartär tid. De anta ett invecklat samspel mellan förändringar av själva jordskorpans höjdläge (von Posts α-effekter) och eustatiska växlingar av havsytan (von Posts ω-effekter). Jordskorpan skulle ej ha höjt sig jämnt som man förut en tid allmänt ansett, utan höjningen skulle ha mer eller mindre regelbundet avbrutits av retardation eller landsänkning — von Post talar i detta sammanhang om elastiska chocker, Gillberg om reversioner och Florin om undulationer.

I motsats till dessa åskådningar står Erik Nilssons uppfattning. Han anser sig ur sitt material endast kunna utläsa jämna och lugna nivåförändringar utan några chocker och utan några mera markerade differentialrörelser mellan olika berggrundsblock. Liknande åsikter ha bl. a. Caldenius, Sandegren och Jan Lundqvist gett uttryck åt.

Frågan om Ancylussjöns natur och tidsutsträckning är alltjämt ett olöst spörsmål. Något väsentligt nytt till belysning av detta problemkomplex har knappast tillkommit från svensk sida under det senaste decenniet.

En del nya iakttagelser ha på senare tid gjorts, som öka vår kunskap om omfattningen av det område, som numera är vattentäckt men som en gång var torrt land, innan den postglaciala transgressionen satte in på Västkusten och ancylus- och litorinatransgressionerna i det baltiska området. Carl Caldenius och Gunnel Linnman (1949) rapportera sålunda om fynd av fossila torrskorpor, dels vid Västkusten (på 14 m djup vid Halmstad), dels i Östersjöområdet (på 6 m djup vid Karlshamn). Kombinerade dansk-svenska undersökningar med Kullenbergslodet (Kullenberg 1954) ha emellertid ej lyckats verifiera förekomsten av fast land under senkvartär tid på större djup i södra Östersjön. De bekanta Kåsebergastubbarna, som anträffats på omkring 35 m djup söder om Skåne, och andra liknande fynd från Östersjöns botten ha ju annars ansetts visa detta. Enligt Kullenberg synas de hittills gjorda rönen snarast ge vid handen, att området under 30 m i södra Östersjön varit ständigt täckt av vatten. Ingen torrskorpa, inga stubbar eller lakustrina sediment ha anträffats. Närmare skånska kusten består däremot bottnen av sand, som vilar på hård morän.

De marina lerornas stratigrafi har angripits av Fritz Brotzen (1951). Han har konstaterat, att foraminiferfaunan i västkustlerorna växlar från skikt till skikt. Verkliga ledformer kunna uppställas, som tydligt skilja senglaciala och postglaciala leror.

Vegetations- och klimathistoria

I en stor del av de skrifter, som behandla nivåförändringarna, har för dateringen av åtminstone vissa kritiska punkter pollenanalys använts. För mera rent vegetationshistoriska utredningar samt för lösande av torvgeologiska och klimathistoriska problemställningar har denna metod tillämpats i ett flertal arbeten. Till skillnad mot tidigare har man nu i många fall — huvudsakligen efter danskt föredöme — börjat använda sig av en mera avancerad form av pollenanalys. Medan man förut i huvudsak nöjt sig med räkning av trädpollen, tar man numera i allt mera ökad utsträckning hänsyn även till pollen av buskar och örter för att få en så fullständig bild som möjligt av vegetationen och dess förändringar. Möjligheten att konnektera och datera pollendiagrammen ökar också i viss grad i samma mån, som antalet pollentyper ökar. Även när det gäller rena dateringsändamål, förtjänar därför dylik avancerad pollenanalys få ökad spridning.

Rent vegetationshistoriskt syfte ha ett par större arbeten av MAGNUS FRIES (1951, 1958). I det förstnämnda av dessa arbeten anser sig FRIES kunna urskilja allerödlager i mellersta Bohuslän. Den postglaciala värmetidens optimum, högvärmetiden, förlägger han till senare delen av mesolitisk tid, ett avsnitt som skogshistoriskt karakteriseras av linden. Redan vid början av yngre nordisk stenålder vill han finna tecken till sämre klimat — den postglaciala klimatförsämringens tid räknar han fr. o. m. nämnda tidpunkt. — I arbetet av 1958 försöker FRIES spåra kulturpåverkan av vegetationen i pollendiagrammen (jfr även MAJ-BRITT FLORIN 1957).

Vid en undersökning av en myr på Tönnersjöheden i södra Halland har det lyckats OLAUSSON (1957) att för första gången påvisa förekomsten av fossil *Ilex* i Sverige. I lager från högvärmetid anträffade han 3 stycken pollenkorn av denna växt.

I Skåne och Blekinge äro flera större torvgeologisk-vegetationshistoriska arbeten i gång. Delvis föreligga resultaten av dessa i manuskriptform (BJÖRN BERGLUND, ERNEST MAGNUSSON). I det stora mosskomplexet nordväst om Ringsjön, framför allt i Ageröds mosse, ha rika kulturlager från mesolitisk tid utgrävts av C.-A. ALTHIN. Bearbetningen av torvprov från denna utgrävning samt av särskilt insamlat material för utredningen av områdets utvecklingshistoria är i gång vid Kvartärgeologiska institutionen i Lund.

Åldersbestämningar med radioaktivt kol

Åldersbestämningar med radioaktivt kol synas på ett lyckligt sätt komma att komplettera pollenanalysen som dateringsmetod. Som redan förut nämnts, ha en rad kol-14-bestämningar utförts på uppenbarligen interglaciala fynd. För senkvartära avlagringar ha redan ett ganska avsevärt antal sådana dateringar publicerats (ÖSTLUND, GEJVALL & G. LUNDQVIST 1956; G. LUNDQVIST 1957; JAN LUNDQVIST 1957, 1958; ÖSTLUND 1957; M. FRIES 1958). Några få av dessa skola anföras. Samtliga värden i fortsättningen anges som årtal f. Kr.

Vid Robertsdal i södra Skåne föreligger tydligen en allerödavlagring: ålder 9025 ± 140 f. Kr. (G. LUNDQVIST).

De submarina tallstubbar, som uppdraggats på omkr. 35 m djup utanför Kåseberga, ha ungefär den ålder, de borde ha, om de vuxit på det ställe där de anträffats. En kol-14-bestämning har gett värdet 7375 ± 120 f. Kr. Ungefär samma ålder har en annan stubbe, som uppfiskats utanför Karlskrona på 38 m djup: 7145 ± 120 f. Kr. (G. LUNDQVIST).

En litorinavall vid Ramsås norr om Kalmar har enligt en kol-14-bestämning av underlagrande torv bildats efter år 5075 ± 110 f. Kr. (G. LUNDQVIST), en datering som går utmärkt ihop med en med andra metoder utförd åldersbestämning av den första litorinatransgressionen i Skåne (ca 5000 f. Kr.; T. NILSSON 1935).

Det pregnanta *Ulmus*-fallet vid mitten av postglacialtiden, vid slutet av den egentliga högvärmetiden enligt FRIES, har daterats med kol-14 på tre ställen i Sverige, dels vid Mogetorp i Södermanland (medeltal ca 3340 f. Kr.; S. FLORIN 1958), dels på två ställen i Varnhemstrakten (3330 ± 110 f. Kr. resp. 3630 ± 110 f. Kr.; FRIES 1958). De tre bestämningarna stämma frapperande väl överens. De ge medeltalet ca 3430 f. Kr. (jfr årtalet 3500 f. Kr. hos T. NILSSON 1935, en siffra, som erhölls genom beräkning av de skånska torvlagerföljdernas genomsnittliga tillväxthastighet).

Ytterligare är att anteckna, att en tydlig försening i granens invandring från norra till södra Sverige synes kunna påvisas. Medan den markanta granuppgången äger rum omkring år 1000 f. Kr. i Norrland, sker samma sak i Värmland inte förrän några 100-tal år senare, ca 200—500 f. Kr. (JAN LUNDQVIST).

Till sist skall ges några nya kol-14-dateringar från Sydsverige. Dessa ha utförts dels av fil. lic. G. ÖSTLUND vid Stockholms kol-14-laboratorium (prov med beteckning St; se ÖSTLUND 1959), dels av fil. lic. INGRID OLSSON vid Uppsala universitets fysiska institution (prov med beteckning U).

Vid Toppeladugård ca 15 km SO om Lund finnes en klassisk lokal med allerödlager, som behandlats redan av HOLST (1906) och som pollenanalytiskt undersökts av mig. (T. NILSSON 1935). I april 1958 togs en serie prov för kol-14-datering av denna allerödförekomst. Allerödlagren, som täckas av ca 2 m yngre dryaslera, bestå av följande skikt: 1) överst av ett tunt lager kalkgyttja; 2) därunder av lergyttja, som uppdelas i en övre och en undre horisont genom ett mellanlager av gyttjig lera; 3) underst av ett tunt lager torvartad s. k. allerödmylla. Kalkgyttjan lämnade efter kalkens utlösning med syra alltför liten organisk återstod för kol-14-datering. Den övre lergyttjehorisonten har gett värdet 9940 ± 180 f. Kr. (St-345), allerödmyllan värdet 10040 ± 200 f. Kr. (St-341).[1] Till jämförelse kan meddelas, att de danska kol-14-dateringarna av allerödlagren i Ruds Vedby ha gett årtalen 8880 ± 200 f. Kr. för slutet av alleröd och 9020 ± 220 f. Kr.—9930 ± 340 f. Kr. för mellersta alleröd och sista delen av äldre alleröd (IVERSEN 1953). Allerödmyllan i den skånska profilen torde i stort sett markera allerödtidens början.

Ifrån sydöstra Blekinge ha två prov, som insamlats av fil. lic. BJÖRN BERGLUND, kol-14-daterats.

I nordvästra delen av den lilla Färsksjön, som är belägen på Torhamnshalvön 14 m ö. h., fann BERGLUND ett utbrett stubblager på sjöns botten. täckt av närmare en meter vatten. Då avloppet är beläget i söder, måste förhållandet i fråga tolkas så, att sjöns vattenyta har stigit på grund av klimatförsämring med ökad nederbörd, varvid skog på stränderna dränkts.

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[1] Vid föredraget lämnades endast en preliminär ålder för allerödmyllan. Det definitiva värdet samt åldern på lergyttjan ha dock införts här. Enligt benägen uppgift av dr ÖSTLUND torde årtalet för lergyttjan vara något för högt; i sjösediment, som bildats i kalkrikt vatten, kan nämligen även den organiska fraktionen innehålla en del äldre kol.

En kol-14-datering av en av stubbarna (en tallstubbe) gav årtalet 1950 ± 80 f. Kr. (St-313). Vattenståndsstigningen kan sättas i samband med en ökning av nederbörden, som allmänt kan konstateras bl. a. i Skåne och som där gett upphov till en av de mest markerade rekurrensytorna (T. Nilsson 1935). Denna utbildades ungefär vid slutet av gånggriftstiden och kan jämföras med Granlunds RY V.

Det andra provet utgöres av svämtorv, rik på pinnar o. d., från en havsvik, Sörevik, sydväst om Karlskrona. Svämtorven förekom på ett djup av 4—7 m under vattenytan mellan underlagrande grovmo och täckande lager av gyttjig lera och gyttja. Enligt pollenanalys tillhör svämtorven understa delen av zon VIII i det skånska zonschemat, nära övergången till zon IX. Zongränsen VIII/IX torde i den baltiska utvecklingen ungefärligen motsvara övergången från yoldiatid till ancylustid, en tidpunkt som brukar ansättas till år 7500 f. Kr. eller något senare. Kol-14-dateringen av svämtorven från Sörevik gav årtalet 7040 ± 140 f. Kr. (St-333). Enligt denna åldersbestämning skulle svämtorven på 4—7 m djup vara endast några få 100-tal år yngre än de nyss omnämnda tallstubbarna, som anträffats på betydligt djupare vatten. Vattenståndsstigningen i södra Östersjöområdet synes ha skett hastigt vid denna tid.

Slutligen ha ett par prov av arkeologiskt material, som insänts av professor Holger Arbman, blivit kol-14-daterade. Då dessa bestämningar även ha geologiskt intresse, meddelas de här.

1) Vätteryd (mellersta Skåne): träkol från kulturlager av döstidsålder. Kol-14-årtal för två prov resp. 2595 ± 140 f. Kr. (U-46) och 2730 ± 170 f. Kr. (U-47).

2) Elinelund (vid Limhamn): träkol från kulturlager av sen Ertebölleålder. Kol-14-årtal: 3360 ± 210 f. Kr. (U-48).

Den sistnämnda dateringen har omedelbart geologiskt intresse, då kulturlagret i fråga — från sen Ertebölletid — låg på insidan av litorinastrandvallen, den s. k. Järavallen, och överlagrades av dennas strandgrus. Järavallen var alltså vid Malmö ej färdigbyggd vid tidpunkten 3360 ± 210 f. Kr. Detta innebär dock intet principiellt nytt. Genom Otto Rydbecks undersökningar veta vi, att litorinagränsvallen i södra Skåne i sina översta delar är av gånggriftstidsålder.

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On Exhalative-Sedimentary Ores. Replies and Discussion

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Introduction. My recent article "A theory of exhalative-sedimentary ores" in this journal (OFTEDAHL, 1958) has resulted in three articles, one by MARMO (1958), one by KAUTSKY (1958), and, finally, one by LANDERGREN (1958).

The first and the last articles are welcomed for their positive criticism and their several suggestions. The article by Kautsky is written in a somewhat different style. Every other sentence could be commented on or corrected. Typical is the error that he thinks that I consider submarine ashes as ignimbrites (KAUTSKY, 1958, p. 284). Naturally ignimbrites result from terrestrial explosions, not submarine.

In the following I discuss a number of problems and critical remarks mentioned in the three articles, and I choose those which are specially fruitful for the advancement of genetical problems.

On granite as the source of ores. MARMO (p. 279) has difficulties in believing in large magma chambers. The seismic investigations do not support the occurrence of such, MARMO writes, but investigations by BOTT (1956) and others indicate that homogeneous granite bodies ordinarily may have dimensions of 20 km or more in diameter and a thickness of about 8 km.

LANDERGREN writes: "It seems, however, remote to the present author that any of the iron ores hitherto studied should be the result of an enrichment and transport of iron solely by the aid of some kind of volatile activity emanating from a "granitic magma chamber" — an imagination from long ago" (LANDERGREN, 1958, p. 289). This statement contradicts what I think are observed facts and undoubted results.

The geologic map of the Oslo region by BRØGGER (1933) shows that continuous bodies of granitic rocks have the following surface areas:

Ca. (5 × 5) km^2, very common.
» (10 × 10) » , also very common.
» (20 × 20) » , some bodies, but maximum.

All geologists who have published on these deepseated rocks agree that they have crystallised from a liquid magma, even if not all of this magma was liquid at the same time. This is what I think of as a magma chamber at some time during the Permian.

It is a fact that in, but especially along the contacts of, such plutonic bodies of granitic and quartz syenitic composition we find small deposits rich in magnetite, hematite, chalcopyrite, sphalerite, galena, manganese minerals, and molybdenite. J. H. L. VOGT and V. M. GOLDSCHMIDT concluded that these deposits were the result of an enrichment and transport of iron etc. solely by the aid of some kind of volatile activity emanating from a granitic magma chamber. They called the emanations gases (see MOREY, 1957, p. 231). I see no reason to change the conclusions of these worldknown authorities.

The most ordinary granite, the Drammen granite, contains about 2 % FeO (Fe_2O_3 counted with FeO for the sake of simplicity). If now only 5 % of this iron could be "left over" from the liquid phase to the gas phase (0.1 % FeO of total rock), quite large quantities of iron could be brought to the surface. In order to illustrate this with a calculation, I assume that all this iron was expelled from the whole of the following magma chambers:

Surface in km²	(5×5)	(10×10)	(20×20)
Volumes in km³			
with depth 1 km	25	100	400
3 »	75	300	1 200
6 »	150	600	2 400
Mill tons of FeO			
with depth 1 km	63	250	1 000
3 »	188	750	3 000
6 »	375	1 500	6 000

In the table above the surfaces of granite bodies are observed facts, and the assumed values for their depths are moderate. An assumed depth of 8—10 km would not seem unlikely. Thus, if only a fraction of the iron supposed to enter into the gas phase could be liberated from the magma chamber, this iron would give rise to iron ores. If liberated into the sea, this iron could result in large ore deposits. The small contact deposits which we observe at the granite contacts are the results of the precipitation effect of very inefficient filters, essentially limestones. And the ores are formed at the outer contacts. If the once existing, thick roof rocks had not been carried away by erosion, much larger contact deposits would no doubt have existed in our days. The only known case of a preserved roof (but a thin one) is the Konnerud area (see GOLDSCHMIDT, 1911, p. 66—86). Here we find small but rich deposits of zinc and lead, iron, and manganese.

It is tempting to make some further assumptions. If the Oslo graben had subsided some more, for instance about 2 000 m instead of the registered average of 1 000 m, the graben surface would have been below the sea. Then the sediments of this sea floor would most likely have been preserved from erosion up to the present day, and within these sediments would have occurred truly exhalative-sedimentary ores which, I assume, would have had really large dimensions.

At present it is not easy to imagine how and why iron should be enriched in the gas phase. The system FeO SiO$_2$, studied by BOWEN and SCHAIRER (1932, p. 200), shows two eutectics, with simultaneous crystallisation of wüstite and fayalite and of fayalite and tridymite. This is in accordance with the generally observed fact that magnetite and small silicate grains fill the interstices between the larger crystals and grains of the granite. Correspondingly iron (and other heavy elements) could be enriched together with some silicate in the gas phase. In the system SiO$_2$—FeO—Fe$_2$O$_3$ (FLASCHEN and OSBORN, 1957, p. 932) the low temperature region consists of the phases fayalite and, with small changes in composition, either tridymite, magnetite, wüstite, or iron. The problem may be illuminated in the near future by laboratory experiments with superheated H$_2$O. The ability of water vapor at supercritical temperatures to dissolve solids has been reviewed and discussed by MOREY (1957) with some new results. It appears that superheated H$_2$O gas is a potent solvent which must play a very important role in late magmatic and metamorphic processes.

MARMO (p. 279—282) stresses the fact that the porphyries adjacent to ore bodies often are not granitic *sensu strictu,* but soda-dominant, and accordingly they and their ore are not derived from a granitic magma. However, the soda dominance is often so pronounced that the conclusion is inescapable that this is not a primary magmatic composition. Contents of 0.3—0.1 % K$_2$O or even less emphasizes this conclusion. This soda dominance must be linked up with the "spilitization" and I assume that this process simply is the interaction between the Na-rich sea water and hot, acidic glass particles. The extent of the soda metasomatism may be governed by the size of the glass particles among many other things (see discussion by GILLULLY, 1935). This solution has been advanced by BESKOW (1929, p. 285) and others, and supported by RITTMANN (1958). This point will be elaborated in a forthcoming paper.

On the ore-forming material. When discussing the various problems of ore formation, it is of upmost importance that one distinguishes between the primary formation and the possible later processes of metamorphism. This is particularly the case with such deposits as the Caledonian ones, which all have been subjected to a more or less pronounced metamorphism.

A re-distribution of the ore-forming material has been postulated by KEIL (1956) for the Upper Silesian zinc and lead deposits, and MARMO (1958, p. 280—281) support the suggestion of a similar explanation for the Norwegian "gangkis" (large copper-bearing pyrite deposits) from the "vasskis" (pure pyrite beds of exhalative-sedimentary origin). Such a process seems less probable for a number of reasons. Pyrite is, together with magnetite, very hard to mobilize during tectonic movements and metamorphisms. If moved, it forms cleat-cut veins where the pyrite accompanies one or many ore minerals. In this way the pyrite is not capable of forming thick, concordant ore bodies with a layering which looks sedimentary.

On the other hand minerals such as calcopyrite, sphalerite, and galena are fairly easily moved and re-deposited, resulting in ores which few fail to recognize as metasomatic, at least in the last stage.

If we should use published results in making reasonable suggestions for the origin of the Caledonian pyrite deposit, as done by MARMO (see above), I would choose to start from three large and admirable monographs, recently published. St. Andreasberg (WILKE, 1952) is a beautiful example of the hydrothermal vein deposits which may form in the roof rocks of a crystallizing granite. Meggen (EHRENBERG, PILZER and SCHRÖDER, 1954) is a most typical exampel of an exhalative-sedimentary ore. This ore is clearly a sediment, and it is intimately connected with keratophyre volcanism. Finally Rammelsberg (RAMDOHR, 1953) serves as example of a more highly metamorphosed, exhalative-sedimentary sulphide ore, quite like many Caledonian sulphide ores. The extensive evidence backing the concluded origin of the ores in these papers can not be lightly discarded, and from these deposits I make the extrapolation to the Caledonian ores in general.

The results of KEIL (1956) are worth discussing. These deposits (now of the Gorny Slask area of Poland) are interpreted as formed from truly sedimentary horizons by mobilization of the sphalerite and galena into adjacent beds of dolomite. Concerning the origin of the ore sediment, KEIL writes (1956, p. 54): "Wenn man schliesslich nach der Herkunft der Erzlösungen bei derartige umfangreiche Erzlagerstätten fragt, so ergibt sich wohl nur eine Antwort die Stappenbeck schon gegeben hat. Sie stammen aus den Erzgängen der ehemaligen Ostsudeten und den ehemaligen Prä-Karpaten." Here remnants of numerous ore veins are still present. "Die Erzlösungen wurden durch Bäche, Flüsse aus diesen Gebirgen in das Muschelkalkmeer gebracht. Bei einem so weit gespannten Bogen des Hinterlandes lässt sich zwanglos die örtliche grossartige Konzentration der einzigartigen Erzlagerstätten auf verhältnismässig eng umrissenen Raum erklären."

This is admittedly a good possibility, but it deserves a discussion. It is hard to imagine how these ore horizons can be so pure and so sharply distributed in the sediments. If the material of the ore was supplied by streams into the ocean, then the material should be transported continuously during the period of erosion, and the ore precipitation should occur together with the sedimentation. That is to say: The ore should be "drowned" in sediment. Now the primary ore beds of KEIL (1956, figs. 10—14) are thin, sharp and quite numerous. What is the mechanism which produces several sharp bursts of precipitation of a material which is constantly supplied? On the other hand submarine volcanism may supply the material in sharp bursts, to be precipitated at once. If the sedimentary origin of the ore material is not supported by better evidence one is tempted to assume a volcanic source, as I have done as a tentative solution for the deposits of Upper Silesia and Mississippi Valley (OFTEDAHL, 1958, p. 16). Simultaneously the same solution has been suggested for the latter province by AMSTUTZ (1958).

Similar doubts may also be thrown on several cases of sedimentary ores not connected with volcanism (point 4 of MARMO, 1958, p. 282). Especially the ores of orogenic zones may be supposed to have a volcanic source even if that is some distance away along the zone. Other cases are naturally more doubtful.

Reply to KAUTSKY. KAUTSKY (1958) opens his criticism with the statement that my publication has "weak foundations"; when generally maintained views are to be replaced by a new hypothesis it should have a solid fundamental backing, he thinks.

This is a philosophical problem, really. If a geologist, after many years of work on certain problems sees a new possible solution to these problems should he present his solution in a short, easily read, preliminary article, for consideration and discussion by his colleagues, or should he wait another five years until systematic observations from a very wide field can back up the solution, then presented in a thick monograph? I prefer the first alternative, KAUTSKY seems to prefer the second. A short article, however, can not convince anybody of anything. It only presents the most important facts in a generalized form and the conclusions which are drawn, and the readers pass their judgement with their own experience as a background. Similarly, C. W. CARSTENS (1932, 1936) presented his views on the Caledonian sulphide deposits, interpreted by him as metasomatic, in short articles.

KAUTSKY thinks that the features I have pointed out are of little importance and that the features he knows especially well from his experience are of genetic importance. It would take too much space to comment on the several points which are difficult to understand for KAUTSKY and easily explained by me and *vice versa*. Only two main points shall be discussed.

KAUTSKY thinks that the Caledonian sulphide deposits are genetically related to structures. They may be a fold crest, a thrust plane, or some other tectonic feature. According to my experience the deposits lie in folded or thrust rocks with a highly varying structural picture; some in strongly folded rocks, some in faintly folded rocks, and some within fairly plane beds. But one feature is clear: tectonic movements have always occurred close to the ore. I see this as a natural consequence of great difference in competence between the ore body and the adjacent rock. But in general I see no genetical relation between ore body and structure. A metasomatic source of the ore from some granite or gabbro or some unspecified source is a misty hypothesis to me. A wholesale transport of a pre-existing ore body to a tectonic position is unlikely because pyrite has such a very low susceptibility to mobilization. This is elaborated by TAUPITZ (1954). He also stresses the point that metasomatic processes and granitization scatter the material and do not enrich it. Thus the tectonic or metasomatic origin seems unlikely to me. Hydrothermal re-deposition results in vein deposits, clearly recognizable as such, and not in concordant, massive and layered ore bodies.

Sulitelma is used as example of an epigenetic deposit by KAUTSKY (1953). I may return to that subject when I have studied the deposit. However, KRAUSE (1956) has recently studied the deposit and gives good evidence for a syngenetic origin.

The second point is the transition from the "vasskis" type of pyrite deposit to the economically important, copperbearing deposits. The first type has been shown in a convincing way to be sedimentary (exhalative-sedimentary) by

Carstens (1922), and Kautsky seems not to disagree. But he repeatedly denies that there are deposits transitional between these two types. This is of course one of the crucial points in the current discussion. It must be admitted, however, that Kautsky's conclusion from negative evidence ("No transitions occur ...") may be excused by the fact that C. W. Carstens repeatedly emphasized the difference between the two types. But he knew about transitions ("Über Kupferhaltige Kiesvorkommen des Leksdalstypus", Carstens, 1942) although he thought they were rare. I know of several transitional cases, and I plan to give a comprehensive documentation of these in a later paper.

Acknowledgement. I am indebted to my colleague, Mr. Paul H. Reitan for criticall/ reading the manuscript.

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On Exhalative-Sedimentary Ores

By

GUNNAR KULLERUD, FRANK M. VOKES, and HUBERT L. BARNES

The paper "A theory of exhalative-sedimentary ores" published by Dr. CHR. OFTEDAHL in Geologiska Föreningens i Stockholm Förhandlingar, Bd. 80, H. 1, p. 1—19, 1958, revives an often repeated hypothesis concerning the mechanism of deposition of "many types of massive, concordant ore beds associated with supracrustal rocks" (OFTEDAHL, 1958).

Parts of this paper have been discussed by Drs. MARMO (1958), KAUTSKY (1958), and LANDERGREN (1958) in this journal, Bd. 80, H. 3, p. 277—282, 283—287, and 288—291, respectively. In these discussions Drs. MARMO and KAUTSKY take issue with the geological evidence for Dr. OFTEDAHL's conclusions and Dr. LANDERGREN points out a few of the geochemical shortcomings. Although many of the inadequacies of this hypothesis have been discussed already, there still remains much pertinent volcanologic and chemical data.

The "theory," presented by OFTEDAHL, "... rests on two lines of indirect evidence: (1) the fact that crystallizing, acid magmas give off gases containing a great number of metals, and (2) the fact that acid pyroclastics are far more abundant than generally recognized and often genetically associated with ores."

Thus observations first of small quantities of various ore minerals near fumaroles or other volcanic vents and second the presence in some ore districts of felsic rocks which at one time may have been tuffs become the basis of a weak hypothesis which by no means has the stature of a theory.

Evaluation of some pertinent volcanologic, chemical, and geological data follows.

a. Volcanologic Data

The observations made by Dr. E. G. ZIES (1924, 1929) in the Valley of Ten Thousand Smokes provide useful information on the concentrations of metals present both in the volcanic gases and the extrusive rocks and the temperatures of deposition of minerals at the volcanic vents. Fourteen metals were found in the incrustations which probably were deposited from halides in the gas. Magnetite containing zinc and possibly lead was deposited near the vents at temperatures well above 250° C, and copper sulfide or sulfides were deposited at 100° to 200° C. Conservative estimates were made by ZIES (1929) of the volume of steam exhaled by the fumaroles in the Valley of Ten Thousand

Smokes. This steam was analyzed and calculated to contain at 100° C: 0.117 % HCl, 0.032 % HF, 0.029 % H_2S, etc. These amounts are equal to 1.25×10^6 tons HCl per year, 0.2×10^6 tons HF per year, and 0.3×10^6 tons H_2S per year (ZIES, 1929). These enormous volumes of gas transported and deposited near fissures at the surface small quantities of metals. ZIES (personal communication, 1958) points out that the observed amount of magnetite deposited in the *entire* Valley of Ten Thousand Smokes might have been as much as 5 000 tons. This magnetite, which was deposited at temperatures well above 250° C, is not stable at low temperatures in the presence of volcanic gases of the composition mentioned above and is readily attacked. For this reason, the magnetite observed near fissures in such areas may not represent the total accumulation. Nevertheless, this tonnage is several orders of magnitude too small to be of commercial importance even several years after the peak of volcanic activity. ZIES (1929) has also shown that the metal content of the pumice is considerable but, although the gases may readily penetrate and react with the disseminated metals, they cannot extract any important quantity of these metals at low temperatures and pressures. Thus volcanic gases when exhaled into the sea contain far too small amounts of metals to meet the requirements of large scale ore deposits.

Data on volcanic gases were also obtained from the Cyclades by RECK, GEORGALAS, and coworkers (1936). The temperatures at the throat of vents of gases exhaling into the atmosphere varied from 680° to 900° C. S, $BaSO_4$, PbS, Ag_2S, etc., in sufficient amounts to be exploited by small mining operations were deposited in fissures near the surface. Large volumes of gases have been observed to exhale from submarine vents. However, aside from insignificant amounts of $Fe(OH)_3$ precipitating when the exhalations react with sea water, no submarine ore deposition was observed. From these well-described examples we may conclude that while some or all of the mineral constituents of certain ore bodies may occur in volcanic gases, the concentrations are many orders of magnitude lower than necessary for extensive ore deposition even from the largest imaginable volumes of volcanic exhalations.

b. Chemical Data

SVERDUP, JOHNSON and FLEMING (1942, p. 195) show that the pH of sea water is below seven only in high H_2S environments. KRUMBEIN and CARRELS (1952) show that at pH less than seven appreciable amounts of iron (meaning amounts in excess of 10^{-4} m/L) can be carried in solution only if it occurs as Fe^{++}, and if the environment is free of sulfide. As a consequence of these conditions the Eh value is fixed within the range of -0.1 to $+0.3$. COOPER (1937) points out that the iron in true solution in sea water is probably less than 2 micrograms/Liter. The deduction made by OFTEDAHL (p. 13), that when volcanic gases enter sea water the ferrous iron goes into solution whereas the ferric compounds are insoluble, is incompatible with the data presented above.[1] The precipitation of Fe^{+++} implies oxidizing environments and Fe^{++}, therefore, would oxidize to Fe^{+++} to keep up with the precipitation rate, as demanded by the equilibrium ratio which is fixed by the pH and Eh. Thus essentially all the iron would be removed from the solution as hydrous ferric oxide or hydroxide. Therefore, only minute quantities of iron can be transported in solution in sea water.

If iron is to be transported, it must be in a colloidal or detrital state. Krumbein and Garrels (1952, p. 16) show that $Fe(OH)_3$ readily forms a gel or colloid. Oftedahl's explanation that the Lower Ordovician sedimentary iron beds in Europe were formed by precipitation of iron from solutions is certainly erroneous and as shown above chemically impossible. It is evident that the source of the iron in these beds could be either colloidal or detrital. From a chemical point of view alone a sedimentary source for the iron is fully as feasible as a volcanic (colloidal) one.

c. Geological Data

Oftedahl's geological argument for an exhalative-sedimentary origin of many ore deposits is: "... the fact that acid pyroclastics are far more abundant than generally recognized and often associated with ores." The association of acidic rocks of volcanic origin (such as welded tuffs) with numerous ore deposits has been known and long since described from a great number of localities. However, such associations are lacking in many of the deposits which Oftedahl postulates are exhalative-sedimentary in origin. Kautsky (1958) points out the lack of such volcanics near the Cu—Fe sulfide deposits of the Rio Tinto district. This association is likewise lacking in the Pb—Zn sulfide deposits of the Mississippi Valley, as well as in all but one of the Lake Superior iron oxide deposits, and in the Rhodesia-Katanga Cu sulfide deposits.

In many localities where tuffs, or acidic rocks which may once have been tuffs,[2] do occur in association with the ore deposits, Oftedahl neglects geological evidence such as zoning, geochemistry (age determinations, isotopic ratios, trace element distribution, etc.), mineralogy, and mineral assemblages. He also overlooks the interpretative values of geological structures. These structures are the most important factors controlling ore deposition and give by crosscutting relations the relative ages of ores and host rocks. Unequivocal geological evidence, pointed out by Kautsky (1958), was, for instance, ignored for the Caledonian ore deposits. The sedimentary "vass-kis" has a very simple mineralogy, and is practically selenium free. The typical Caledonian sulfide ores have a complex mineralogy, are relatively high in selenium, were formed at about 500° C, and display tectonic linear features governed by the lineation in the rocks which was produced by deformation during the orogenic stage of the geosyncline's history.[1]

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[1] Oftedahl (Fig. 2) applied an Eh *versus* pH diagram given by Krumbein and Garrels (1952) for a discussion of the stability relations of pyrite, siderite, and hematite. It should be noted that the stability boundaries given by Oftedahl as curves in reality are straight lines. The diagram should also include magnetite as well as pyrrhotite. Huber (1958) presents a more complete discussion of the stabilities of precipitates pertinent to this discussion and given a pH *vs.* Eh diagram based on more recent thermodynamic data.

[2] It is often difficult to determine whether such rocks were deposited as tuffs.

It would require excessive space to discuss the origin of each of the ore deposits mentioned and classified as exhalative sedimentary by OFTEDAHL. Furthermore it would be of little merit to do so because:

1. Volcanic data show that sufficient amounts of metals to produce large scale ore deposits are not transported in gas exhalations.
2. Chemical data show that sufficient iron for an ore deposit cannot be transported in solution in sea water.
3. Geological data presented by Drs. MARMO and KAUTSKY and in the present discussion have shown that in the deposits cited by OFTEDAHL, the ores are rarely contemporaneous with the host rocks and even more rarely also associated with contemporaneous volcanics.[2]

In summary the combined volcanological, chemical, and geological data presented in the preceding discussions show conclusively that extensive ore deposits are not of an exhalative-sedimentary origin.

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[1] OFTEDAHL classifies the Vigsnes deposit as a primary exhalative-sedimentary ore. Since we feel he confused this locality with the Lillebö deposit on Stordöy, Norway, we will make no comment on this statement.

[2] From a purely geological viewpoint the Soudan deposit of the Lake Superior district and possibly the »vass-kis» deposits of Norway may fit this old hypothesis now advocated by OFTEDAHL.

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Notiser

Aktuella frågor i Kirunatraktens geologi

Av

PER GEIJER

De kommentarer, som av mig anfördes till R. FRIETSCHS föredrag på Geologiska Föreningens decembersammanträde 1958, kunde av tekniska skäl ej refereras i sagda års sluthäfte av Förhandlingarna och framläggas därför nu i denna form.

Sedan S. G. U:s regionala undersökning av Norrbottens läns urberg hade nått kontakt med området för detaljundersökningarna omkring Kiruna 1905—1909, ha de i arbetet engagerade geologerna med mig diskuterat de motsättningar i uppfattningen av stratigrafien, som hade framträtt. Någon från båda utgångspunkterna acceptabel lösning kunde emellertid ej uppnås. Sedan O. H. ÖDMAN framlagt den regionala undersökningens resultat (S. G. U. ser. Ca nr. 41) ha därför mina synpunkter presenterats i en uppsats uti föregående häfte av dessa Förhandlingar.[1]

Vad först angår förhållandet emellan Kurravaarakonglomeratet och porfyrerna, så betonades av mig i diskussionen efter Frietschs föredrag särskilt nödvändigheten att, såsom ett första steg att föra saken vidare, få genom en serie bilder klarlagt, huru man, med utgångspunkt från antagandet att porfyrerna äro äldre än konglomeratet, vill tänka sig bergarternas ursprungliga fördelning och huru denna har kunnat överföras till den nuvarande.

Ifråga om Vakkoseriens ställning (inom det centrala Kirunaområdet) överensstämma de av FRIETSCH framförda synpunkterna, åtminstone i huvudsak, med mina egna.

Såsom ett särskilt aktuellt studieobjekt i Kirunatrakten ville jag framhålla blodstenarna i »Undre Haukikomplexen». Den omvandling av bergarterna, som har gett upphov till dessa malmer, är med sin nybildning av kvarts, sericit, karbonat, järnglans, tungspat, turmalin, m. m., en typisk hydrotermal process, men är geokemiskt märklig genom den nästan fullständiga frånvaron av sulfidsvavel. Sådant representeras här endast av en kvantitativt sett ytterst obetydlig, men påfallande spridd mineralisation av kopparglans och bornit. Denna förekomst bör jämföras med de små gångar, ibland turmalinförande, med bornit och kopparglans, som uppträda i samband med Kiirunavaaras järnmalm. Att en hydrotermal järnmalmsbildning av Haukiblodstenarnas typ är en normal — om också blott i vissa områden förverkligad — fas av samma geologiska utveckling, som har givit upphov till apatitmalmerna av Kirunatyp, framgår av flera förekomster i liknande sammanhang. Särskilt framhölls den kända fyndigheten Pilot Knob i Missouri (jfr G. F. F. 36: 166), där man bl. a. har en exakt motsvarighet till vissa former av Haukikomplexens egendomligaste led, de breccie- eller konglomeratartade blodstenarna. Då numera förekomsten av »fragmentblodstenar» vid Svappavaara har riktat uppmärksamheten på besläktade malmformer, vore det mycket önskvärt att få den ca 50 år gamla undersökningens resultat kompletterade med stöd av nya metoder och nya synpunkter. Bl. a. bör en undersökning av polerprov kunna klarlägga, i vad mån verkliga konglomeratbildningar föreligga.

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[1] Genom ett missförstånd råkade därvid felaktigt uppgivas, att Frietsch skulle ha funnit gränsen mellan Kurravaarakonglomeratet och porfyrerna vara ett (brant mot nordväst stupande) förskjutningsplan. Såsom FRIETSCH framhöll i sitt föredrag, anser han emellertid att planet ifråga markerar en primär kontakt. För min del måste jag dock hålla före, att detta plan redan på grund av sin stupning måste utgöra en förkastning, låt vara att rörelsen längs densamma ingalunda behöver ha varit betydande.

Om åldersställningen av Kirunaporfyrerna

Av

NILS SUNDIUS

Till mitt inlägg i diskussionen efter Fil. lic. R. FRIETSCH's föredrag den 7/10 om Kirunaområdets geologi anhåller jag att få foga följande komplettering, som även innehåller en del data beträffande historiken över områdets geologiska utforskning.

Det är i urberget en ej ovanlig sak, att då kartan över ett område sammanställes, uppkomma svårlösliga stratigrafiska problem, även om området, såsom i förevarande fall, är mycket detaljerat kartlagt och nya hällar knappast äro att förvänta. Den kartbild, som den nya rekognoseringen i Kirunaområdet resulterat i, skiljer sig också icke i något väsentligt från den som framlades för över 40 år sedan av Dr N. ZENZÉN och mig, och samma ålderskombination, som nu presenteras, var även då under övervägande.

Genom ZENZÉNS arbeten norr om Torneälven hade Vakkoseriens bergarter utskilts och diskordansen under dem kartlagts. Ävenledes var han övertygad om att en betydande störning — väl närmast en förkastning — måste finnas i trakten av Torne älv på grund av omöjligheten att direkt kombinera lagren och berggrundsbyggnaden å ömse sidor av älven, även om den starka jordtäckningen försvårade ett exakt fixerande av störningslinjen. Den utlades därför ej på kartan utan skulle diskuteras av ZENZÉN i hans tillämnade skrift. Tyvärr blev denna ej färdigställd. ZENZÉN hade även erfarenhet av den likhet, som Kirunagrönstenarna erbjödo med de till Vakkoserien hörande grönstenarna. Hans åsikt var därför, att Kurravaarakomplexen borde hänföras till Vakkoserien och att den diskordans, som påvisats norr om Torneälv under serien, skulle fortsätta söder om älven väster om Kirunagrönstenarna. Å andra sidan voro varken hällar eller block av något bottenkonglomerat kända här. Vidare var en intrusion av hyperstenförande gabbro, likartad med den gabbro, som iakttagits väster om Kirunagrönstenarna och vid Kalixfors, känd från Pahtasvaara. Härtill kom den starka skapolitiseringen, som av mig hänfördes till området gabbrogranitbergarter. Det avgörande momentet var emellertid porfyrernas ställning. Om Kurravaarakomplexen överfördes till Vakkoserien, skulle även porfyrerna medfölja, och vi tänkte oss då, som även de yngre geologerna f. n., att porfyr-leptitformationen i Norrbotten utgjorde en enhet. Av denna anledning hänfördes Kurravaarakomplexen till pre-Vakkoåldersgruppen.

Problemställningen har förblivit densamma nu som då. De yngre geologerna ha blott försökt lösa den på ett avvikande sätt. De ha hänfört Kurravaarakomplexen till Vakkoserien. Däremot vilja de bibehålla porfyrernas äldre ålder, och såsom förklaring till den isoklinala, konkordanta lagerställning, som porfyrerna intaga i Kirunaserien, ha de uppställt en teori om en äldre porfyrhorst, som existerat vid tiden för Vakkoseriens bildning, på ömse sidor om vilken Kurravaarakomplexen och undre Haukiserien avlagrades, varefter porfyrhorsten pressades mot väster och porfyrerna kommo att få det konkordant isoklina läge i Kirunaserien, som de f. n. intaga. Teorien är helt hypotetisk och måste nog betecknas som ganska äventyrlig och osannolik.

Inför den samstämmiga övertygelsen, först av ZENZÉN och sedermera av de yngre geologerna, att Kirunagrönstenarna på grund av utseende och beskaffenhet måste parallelliseras med Vakkoseriens bergarter, synes det rimligt att tro, att så bör vara

fallet. Själv har jag ej sett Vakkobergarterna norr om Torne älv i fält. Men om detta är riktigt, blir Kirunaporfyrernas ställning ytterst svårförklarlig. Åtminstone så länge man fasthåller kravet på en enhetlig porfyr-leptitformation i Norrbotten. Det som f. n. synes vara angelägnast beträffande vidare undersökningar i Kirunaområdet, torde därför vara en åldersbestämning av porfyrerna samt av Kurravaarakomplexens bergarter och av porfyr-leptit av säkert prekarelsk ålder.

Nochmals π

Von

HANS J. KOARK

> Qui tacet, consentire videtur
>
> BONIFACIUS VIII

In einem Hinweise (L 1) machte der Verfasser darauf aufmerksam, dass π nach dessen ursprünglicher Definition von SANDER (L 2, 3), bei tektonischen Analysen zur Kennzeichnung tautozonaler Flächengefüge zu verwenden ist und nicht als Synonym für den s-Flächen-Pol, so wie von M. LINDSTRÖM (L 4, 5) und P. G. HJERN (L 6) gehandhabt.

In einer Entgegnung von M. LINDSTRÖM (L 7) bestreitet dieser die der SANDER'schen Definition vom Verfasser zugeschriebene Bedeutung und lässt durchblicken, dass es sich bei dieser Meinungsverschiedenheit um eine Lapalie handelt. Nun, eine solche Bewertung ist natürlich relativ und LINDSTRÖM's persönliche Einstellung. Dem kann ich doch nicht beipflichten, da zwischen dem SANDER'schen und LINDSTRÖM'schen π-Pole, ausser derer grundverschiedener geometrischer Sinne, immerhin für die Durchstosspunkte der π-Lote in der Projektion ein Differenzwinkel von 90° besteht, der den Lesern, die solche Abhandlungen verstehen sollen, nicht gleichgültig sein kann.

Dem aufmerksamen Leser meines Hinweises und LINDSTRÖM's Antwort wird aufgefallen sein, dass meine Anmerkung der Sache galt; die Rückäusserung des Antwortenden hingegen, ob die SANDER'schen Definitionen von ihm richtig oder unrichtig gelesen wurden.

Es ist nicht so ungewöhnlich, dass aus dem Zusammenhang herausgerissene Sätze scheinbare Unklarheiten mitsichbringen, so wie der zur Frage stehende von SANDER (L 3, S. 132): „Bei Einzeichnung der Ebenenlote π fallen diese Lote, in kennzeichnender Weise gestreut, wahrnehmbar auf einen Grosskreis, den π-Kreis der betreffenden Ebenen.“ Das steht in einem Abschnitt, der speziell der geometrischen Behandlung tautozonaler Flächengefüge gilt und ist in diesem Zusammenhange zu verstehen. Falls es überhaupt eine Unklarheit gibt, so beseitigt diese der schon in L 1 zitierte SANDER'sche Satz aus L 2, 3: „Im betrachteten Falle ist dieser s-Pol-Kreis als π-Kreis bezeichnet, sein Lot als π-Achse und der Ort von π in der Projektion als π-Pol.“ Wenn also bei SANDER: „s-Pole (π)“ zu lesen ist (vgl. L 7), so ist immer von der Mehrzahl die Rede und das in Verbindung mit tautozonalem Flächengefüge, wofür eben in Klammer π gesetzt wird. Das gilt auch für das von LINDSTRÖM (L 7) unglücklicherweise als Beweis für die Richtigkeit seiner Ansicht angeführte Diagramm bei SANDER (L 3, Abb. 41, S. 138). Für den Eingelesenen wird bei Betrachtung desselben sofort deutlich, dass die Beschriftung im Diagramme „s-Pole (π)“ nicht einem Pole, wie LINDSTRÖM's schwebender Formulierung zu entnehmen ist, sondern deren 8 gilt, die in der Projektion einen deutlichen Zonenkreis bilden, d. h. einen SANDER'schen

π-Kreis (darum π in Klammer!), dessen Pol im Netz, wie schon gesagt, mit jenem von LINDSTRÖM um 90° divergiert. (Für den mit der Sache weniger vertrauten Leser gibt METZ in seinem Lehrbuche (L 8, besonders S. 40) eine schnelle und einfache Einführung.)

Fachlich interessiert doch weniger, ob eine Definition an bestimmter Stelle möglicherweise sprachlich unscharf formuliert ist, was trotz allem im vorliegendem Falle nicht zutrifft, sondern vielmehr, ob die vorgenommene Umdeutung einem bestimmten Zwecke dient und wenn ja, welche Fortschritte damit erzielt wurden. Das ist der Kern der Sache und ich kann bei bestem Willen in der „Umtaufe" der beiden Verfasser nichts anderes sehen, als dass sie Verwirrung in das Begriffinventar der Gefügekunde bringt, weil meines Erachtens damit einer wichtigen und allgemein gebräuchlichen Definition (π zur Kennzeichnung tautozonaler Flächengefüge) der Sinn genommen, und ausserdem einem anderen geometrischen Datum (s-Pol) eine vollkommen überflüssige und sinnlose zweite Bezeichnung (π = s-Pol) hinzugefügt wird. — Sollte ich hierin doch Unrecht haben, würde es mich für die Sache freuen, des Besseren belehrt zu werden.

Literaturverzeichnis

1) H. J. KOARK, 1958: Zur Definition von π bei tektonischen Analysen. G. F. F., Bd 80, H. 3.
2) B. SANDER, 1942: Über Flächen- und Achsengefüge (Westende der Hohen Tauern, III. Bericht). Mitt. d. Reichsamtes f. Bodenforschung, Zweigstelle Wien, 4.
3) — 1948: Einführung in die Gefügekunde der geologischen Körper. 1. Teil. Wien und Innsbruck.
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7) M. LINDSTRÖM, 1958: Regarding the definition of π. G. F. F., Bd 80, H. 4.
8) K. METZ, 1957: Lehrbruch der Tektonischen Geologie. Stuttgart.

The Last of π

By

MAURITS LINDSTRÖM

According to KOARK, π is the normal of a π-circle, defined by the normals of tautozonally arranged s-surfaces. According to myself (LINDSTRÖM 1958, and papers cited therein), π is the normal of an s-surface (as π may be plural, it may of course also refer to several s-surface normals). Both of us rely on SANDER (in my case only SANDER 1948) for the definition. I have suggested that SANDER 1948 should be the ultimate authority in this terminological question, and KOARK has not contradicted this.

I lean heavily on a number of instances in which SANDER 1948 has defined π by apposition (LINDSTRÖM 1958). KOARK, however, maintains that the appositional definitions occur in contexts which make them take on a sense different from that read into them by me. Now, an apposition covers the noun it is apposed to, which-

ever the context or language may be. In "die Stadt Hamburg", "die Stadt" is apposition, and "Hamburg" is defined by this apposition. In SANDER's expression (1948, p. 132) "die Ebenenlote π", "die Ebenenlote" is apposition, and defines "π". An apposition may also be placed after the expression it determines, occasionally in parenthesis, for instance "carbon dioxide (CO_2)", in which case "(CO_2)" is apposition to "carbon dioxide". Compare SANDER's "s-Pole (π)". A further case, not cited previously by me, is found in SANDER 1948 (p. 144), and reads thus, "Namentlich der Vergleich der Häufungsbilder für β, B und π (s-Pole) ist bei der genaueren tektonischen Analyse eines Bereiches durchzuführen" — etc.

It is thus indubitable that SANDER 1948 contains some expressions that clearly define π as s-normals, and other expressions that are most reasonably interpreted in the same sense. The expression "Im betrachteten Falle ist dieser s-Pol-Kreis als π-Kreis bezeichnet, sein Lot als π-Achse und der Ort von π in der Projektion als π-Pol "twice quoted by KOARK (1958 and above) as a definition of π is analyzed in detail by me (1958), and found to be partly nonsensical. This analysis is not mentioned by KOARK (above).

Having reached this point in the enquiry, I am ready to refute KOARK's remarks against my interpretation of SANDER as absurd. However, the matter is not as simple as this. The phrases from SANDER 1948 so far brought forth in our dispute are either problematic, or identical with the definition of π used by me. However, now it must be said that the dispute would not have reached this stage, had KOARK and I read SANDER 1948 thoroughly enough, lately. Or should I speak only for myself? The reader is directed to fig. 66, p. 178, in SANDER 1948. In this figure, π is definitely used in the sense advocated by KOARK.

Thus, it is evident from a logical examination of SANDER's text that π is therein defined and (or) used in two opposite senses: as the normal to the π-circle, and as the s-normals that may constitute a π-circle. As pointed out by KOARK, π in the first sense makes 90° with π in the second.

For this reason, I shall from now on drop the use of the symbol π in my work, and would advise others to do the same. In any case, the one who will use the symbol π in tectonics must take the trouble to define it.

At last a few words that do not deal with the matter at hand, but the more with discussion in general, and particularly with geological polemics. There are three good reasons to keep out all comments on personal attitudes. Firstly, that the little time we have is the most effectively wasted over irritation against others. Secondly, that ours is a small profession in a small country. We want our colleagues as friends. Thirdly, that arguments on matter are important, but psychological reflexions are hardly so, at least not in geology. — Thanks for an interesting discussion!

(For references, see KOARK's article "Nochmals π", above.)

Recensioner

HENRY V. HOWE and LAURA LAURENCICH: Introduction to the study of Cretaceous Ostracoda. Louisiana State University Press, 1958, 536 pp, numerous illustrations. Price $ 7.50. Published October 26th, 1958.

Henry V. Howe's valuable "Handbook of Ostracod taxonomy" (see Hessland, G. F. F., 1955, p. 441) is now followed by a worthy successor, written in conjunction with Laura Laurencich.

Over recent years ostracod research in connexion with oil field stratigraphy has risen to the same order of magnitude as that on foraminifera. Yet despite this, no textbook of the type written by Glaessner (1945) for the foraminifera, nor a handy catalogue of genera like the one issued later by Cushman (1950) is available for the use of students and research workers in the field. The first attempt at an organization of the information available was made in the catalogue of names published by Howe in 1955, and referred to above. There is also a "Catalogue of Ostracoda" at present under production by Ellis and Messina. But at the time of writing it is still principally concerned with Paleozoic species. The field of Cretaceous ostracoda has been patchily and unevenly studied. There are the early works by Jones, Bosquet, Reuss, and Cornuel, for example, and more recent monographs by Van Veen, Triebel, van den Bold; there is also a useful guide to more common ostracod genera by Grekoff. Most information, however, must be gleaned from various small, often rather inaccessible articles. Howe's and Laurencich's book is therefore very timely and valuable, not the least as a valient attempt has been made to include Russian genera and species up to the end of 1956. Research on Mesozoic and Cenozoic ostracoda has been greatly intensified in the Soviet Union of recent years, particularly in connexion with the Petroleum Research Institute (Vnigri) in Leningrad. Numerous papers by Mandelstam, Sjaparova, Ljubimova, Katz and Schneider, to mention just a few workers, are invaluable contributions to our knowledge of the group and greatly aid correlation throughout the world. Although incomplete, the names included by Howe and Laurencich will greatly assist workers in the field, who are not fortunate enough to have ready access to the Soviet publications, even if the problem of translation of the generic diagnoses from the Russian provided in most cases an insurmountable difficulty for the authors. Pertinent parts of the recent monographs by Grekoff, Keij and Wagner are also included, even though these do not always specifically deal with the subject at hand.

The book received its inception in connexion with an article prepared by the two authors for the 20th International Geological Congress; it is contributed as a book of reference to what is known of Cretaceous Ostracoda up to the end of 1956 and, in a few cases, 1957. Although the work has had its roots in the card-index kept for many years by Howe, it is more than a mere list of species and literature, for brief analyses and drawings of most forms are supplied.

A short treatment of the ostracod carapace is given as a preliminary to the taxonomic section. In connexion herewith a most useful illustrated summary of the various terms applied to hinge structures is supplied and also a discussion of the taxonomic implication of the muscle scars. The alphabetically arranged list of genera and species, with accompanying short diagnoses and ink drawings make up the central portion of the work. Each genus is listed together with its type species, author, year of publication and page, type stratum where known, and range. In many cases short synonymies are given and the subfamilial designation is incorporated in the analysis. The species attached to the genus follow and they are provided with short diagnoses and figures. The figures are mostly adequate and, although a few supply details of the finer structures, most are habitus pictures, taken from original type material. It might have been helpful to have included a larger number of pore canal diagrams and hinge drawings, but the authors have been strongly limited by the space problem, and such features are usually mentioned in the descriptions.

The taxonomic approach is in accordance with the most modern views on the subject, even if occasional practices are open to criticism. For example, the retention of the name *Archicythereis* Howe, 1936, as a sort of zoologic form genus for certain juvenile forms (the genus was grounded on a molt). It is open to dispute whether a handbook of this kind should be made a vehicle for the erection of new genera. The authors propose four new generic categories, which the reviewer here lists for the information of the reader, as they are easy to overlook, since there is no collective reference to them: They are:

Kalyptovalva Howe and Laurencich: type species *Cytheridea ovata* Bosquet (p. 364).

Kikliocythere Howe and Laurencich; type species *Cypridina favrodiana* Bosquet (p. 368).

Netrocytheridea Howe and Laurencich: type species *Cypridina fusiformis* Bosquet (p. 432).

Phacorhabdotus Howe and Laurencich; type species *P. texanus* Howe and Laurencich (p. 457).

Printing errors occur here and there and an occasional generic name has been distorted (for example, *Probuntonia* instead of *Protobuntonia*), but these lapses are not mentionably irritating. As regards the list of literature it is surprising to see that nothing of Triebel is included after 1952 and Ruggieri is represented by only two titles, even if his production has been concerned with younger species. For example, such an important paper as Triebel's (1954) "Malm-Ostrakoden mit amphidontem Schloss" is not listed, and Hornibrook's (1953) "Tertiary and Recent marine Ostracoda of New Zealand" appears to have been omitted in the systematic part, although listed in the structural section; even though this monograph is primarily concerned with younger material, some of the genera erected occur in the upper Cretaceous (*Bythoceratina*, for example). Oertli's important monographs have also been left out.

These are, however, small defects that do not detract from the usefulness of the volume as a whole and which may be easily remedied in a second edition. The "Introduction to the study of Cretaceous Ostracoda" is a "must" for all specialists in the field of Mesozoic and Cenozoic ostracoda and will no doubt also prove useful to students participating in advanced university courses on micropaleontology.

R. A. Reyment

CHARLES B. OFFICER: *Introduction to the Theory of Sound Transmission. With Application to the Ocean.* McGraw-Hill Book Company, Inc., VIII + 284 pp., 1958. Price 77 s. 6 d.

This book is another contribution to the famous series in the geological sciences of McGraw-Hill, which now consists of eight volumes, each written by outstanding authorities in their fields. In the announcement of this book it is said to be the first to be published on the theory of sound transmission since 1894. Even if this statement is not quite true, there is no doubt that this book has got an important place to fill. The author, Charles B. Officer, has earlier been associated with the Lamont Geological Observatory of Columbia University, New York, well-known for extensive geophysical research, including elastic wave propagation phenomena. The author has conducted extensive investigations in the field of this book as well as in related fields — both theoretical and experimental.

The book, having the character of a text-book, consists of six chapters. The first two contain basic, introductory theory. Starting from the elements of elasticity theory, a derivation of the elastic wave equations is given and solutions given for particular cases. Formulas for sound velocity under adiabatic and isothermal conditions are derived; various energy relations are given; the use of velocity and displacement potentials is thoroughly explained. Although the treatment is limited to small displacements, a brief theory of waves of finite amplitude and of shock fronts is given. There are two main methods of solving wave propagation problems: in terms of wave surfaces and rays or in terms of normal modes. The two methods and their limitations in use have been given an extensive treatment.

Chapters 3 and 4 deal with sound transmission in shallow water and in deep water respectively. In case of shallow water (depth less than 100 m) there is usually no regular variation of sound velocity with depth, whereas for deep water (depth between 3 000 and 7 000 m) there is generally a regular variation with a minimum velocity at some depth, forming a wave guide. In both cases the transmission problems are treated both by the ray method and by the normal-mode method. The ray solution is applicable to wave-lengths approx. 1/10 of the depth and shorter, whereas the normal-mode solution can be used for wave-lengths of the order of half the depth of water or greater. For shallow water, ray solutions are given assuming different velocity-depth relations. It is shown that the shape of a pulse is changed upon reflection from a boundary. Usually the discussion is made both for a simple harmonic source and for the generalisation to a pulse source. In the case of deep water, the ray method is able to deal with the given velocity-depth curve, including a sound channel, whereas the normal-mode solution is given for a constant sound velocity in each layer. It is emphasized that normal-mode methods for a velocity varying with depth will encounter great difficulties. Some cases of near-surface transmission with depth-dependent velocity are specially investigated.

Chapter 5 is termed Reflectivity, and deals with problems at acoustic boundaries: the solution for a point source near a plane boundary leads finally to theoretical expressions for the direct arrival, the reflection arrival, and the refraction arrival; reflections from a finite layer with a rapid change in velocity, from an elastic (rather than a fluid) medium, from a corrugated boundary, from a porous medium, from a boundary with continuous acoustic impedance (of importance in architectural acoustic problems), and from three layers are among the topics studied. Application is made to echo soundings of ocean bottom topography and to geophysical reflection and refraction methods of crustal exploration.

Chapter 6 deals with Attenuation. There are two groups of attenuation phenomena: absorption losses and material dispersion due to the physical properties of a homogeneous fluid medium (viscosity, thermal conduction, porosity), and scattering and diffraction. The general solution for scattering and diffraction is derived and special applications then made.

The book is meant to be an introduction to its field and is commensurate with the level of a senior undergraduate to first year graduate course. Some knowledge of Bessel and Hankel functions and of contour integration in the complex plane is necessary, just to mention some examples. It is a merit of the presentation that thorough mathematical derivations have been given in almost every case and very little is given without further explanation. A knowledge of the content of the book will be enough to follow the published literature in the field. For this reason the book will serve the purpose of a basic course for those who intend to do research in this field. But it has also a much wider application: every research worker concerned with elastic wave propagation problems, especially seismologists, will find the book a valuable tool in their work. Moreover, it has a given place in teaching and as an orientation to everyone interested in the field, even if he does not intend to do research.

The text is meant to be a theoretical treatment. Therefore the practical and observational side, even if important and varied, has got only limited description. Examples are the conditions of temperature and salinity in the oceans of importance for the sound velocity variation with depth, furthermore discussion of echo sounding, and of geophysical reflection and refraction profiles (which may appear a little out of place in this text). A discussion of the T phase would have been appropriate, which is unfortunately missing in the book.

The most outstanding merit of the book is the extreme clearness of the presentation, *e. g.* every chapter starts with a review of the problems to be studied so that the reader is at no moment lost among the formulas; very clear explanations have been given to every concept or method introduced, as the difference between wave velocity and group velocity or between the applications of the ray method and the normal-mode method; furthermore, the author has in every instance clearly explained the physics behind the formulas, frequently giving parallel derivations from the mathematical and the physical side. The figures (189 in all) are very instructive. These are just a few examples, but obviously the clear presentation makes this book particularly valuable as an introductory text-book to all kinds of elastic wave propagation problems.

Unfortunately, the presentation is somewhat obscured by misprints, partly due to a too careless proof-reading, partly due to oversight. The reviewer has found in all about 60 misprints or mistakes in the book. Nearly all of them unfortunately occur in the mathematical formulas and only a few in the text or in figures. Even if the following list may not be complete, it may be of value to readers of the book, even more so as the book is intended as an introduction to its field and will be used by people who may find the misprints confusing.

P. 4, line 10 from above, read $^1/_2\ \varepsilon_{yz}\delta z$ instead of $\varepsilon_{yz}\delta z$.

P. 4, line 11 from above, read $^1/_2\ \varepsilon_{yz}\delta y$ instead of $\varepsilon_{yz}\delta y$.

P. 6, line 10 from above, read $F(x + \dot{u}\delta t, y + \dot{v}\delta t, z + \dot{w}\delta t, t + \delta t)$ instead of $F(x + \dot{u}\delta t, y + \dot{v}\delta t, z + \dot{w}\delta t)$.

P. 17, the statement at the top *may* give the erroneous impression that heat Q is a function of the gas condition.

P. 21, line 12 from above, read. Eq. (1—9) instead of Eq. (1—16).

P. 33, Figs 1—12 and 1—13, read $\dot{u}_1$ and $\dot{u}_2$ instead of u_1 and u_2.

P. 47, eq. (2—8), right-hand side, read $= n^2$ instead of $= 1$.

P. 54, Fig. 2—11 (c), coordinates should be expressed in p and η.

P. 56, lines 7, 8, 13, 14, from above reference should be to Fig. 2—12 instead of Fig. 2—11.

P. 62, Fig. 2—18, the curve is not a simple harmonic curve as supposed, but something else which has been easier to draw (this applies also to p. 63, Fig. 2—19, and p. 103, Figs 3—25 and 3—26).

P. 63, eq. (2—96), read ω instead of w.

P. 67, line 12 from below, read $\Psi(o, t)$ instead of $\Psi(x, o)$.

P. 68, line 11 from above, read $f(z)$ instead of $f(x)$.

P. 73, eq. (2—133), last term, read r_1 instead of r.

P. 80, line 11 from below, read ... or $c_1 > c_2$ and also $\varrho_1 c_1 > \varrho_2 c_2$ instead of ... or $c_1 < c_2$ and also $\varrho_1 c_1 < \varrho_2 c_2$.

P. 84, lines 6, 8 from below, read increases instead of decreases.

P. 94, line 10 from above, read more grazing instead of less grazing.

P. 100, line 9 from above, surface and bottom should change place.

P. 100, line 17 from below, read $\Theta_0 = 90^\circ$ instead of $\Theta_0 = 0^\circ$ with corresponding changes in following lines.

P. 106, eq. (3—24) last line, read $T < 0$ instead of $T \leq 0$.

P. 107, Fig. 3—27, the numerical values of ε in the figure should be multiplied by 2 in order to correspond to the definition of ε in this book. The figure is copied from a paper, where ε was not defined in the same way as here.

P. 108, line 15 from above, denominator should be 2π instead of π.

P. 108, line 5 from below, read a_2 instead of a_1.

P. 112, eq. (3—31), last expression but one, read $r' - r$ instead of $r - r'$; last expression should have a minus-sign instead of plus.

P. 115, eq. (3—40), read plus instead of minus.

P. 121, line 7 from above, $=$ should be inserted at the left-hand end of the line.

P. 121, line 10 from above, read V in denominator instead of H.

P. 128, eq. (3—80), last equation, read ∇^2 instead of Δ^2.

P. 129, line 5 from below, (3—85) should be excluded, as only (3—86) and (3—87) are used.

P. 130, eq. (3—89), expression for D, read $e^{i\beta_2 H}$ in numerator instead of $e^{-ik\beta_2 H}$

P. 130, eq. (3—93), a factor b should be introduced on the right-hand side.

P. 131, line 6 from below, eq. (3—96), read

$\ldots [e^{-i\beta_1 (z-d)} - e^{-i\beta_1 (z+d)}] \{1 + \ldots$

instead of

$\ldots \{[e^{-i\beta_1 (z-d)} - e^{-i\beta_1 (z+d)}] \ldots$

P. 141, line 2 from above, the exponent should be $-\frac{1}{2}$ instead of $\frac{1}{2}$.

P. 141, Fig. 3—45, the abscissa is H/λ which should be indicated.

P. 142, Fig. 3—46, read Airy instead of airy.

P. 159, Fig. 4—16, the limiting ray should be tangential to the bottom.

P. 165, eq. (4—19), first term, read ξ in denominator instead of ζ.

P. 173, line 3 from above, WKBJ approximation should have been briefly explained.

P. 176, eq. (4—58), term $2(l - \lambda_2)^{1/2}$ should have plus-sign instead of minus.

P. 177, line 4 from below, read Eq. (4—61) instead of Eq. (3—61).

P. 183, line 8 from above, read β_n instead of βn.

P. 198, eq. (5—68), second expression, lower integral limit should be $k_2, -i\infty$ instead of $k, -i\infty$.

P. 198, line 4 from below, read (5—68) instead of (5—66).

P. 203, eq. (5—96), 3rd and 4th conditions valid for $x = h$ instead of $x = 0$.

P. 205, Fig. 5—10, all numerical values necessary for the construction of this graph, using eq. (5—98), have not been given in the text.

P. 206, eq. (5—109), expression for m_2 should have minus before the radical instead of plus.

P. 206, line 6 from below, read Eq. (5—98) instead of Eq. (5—99).

P. 206, eq. (5—111), read l instead of k.

P. 207, upper formula, read ω instead of w in second expression.

P. 209, eq. (5—116), expression for $(\sigma_{xz})_2$, read w_2 instead of ω_2.

P. 210, eq. (5—123), second formula, read c_1 instead of c.

P. 215, lines 5, 6 from above, less and greater should change place.

P. 221, eq. (5—177), denominator should be $4h$ instead of $4l$.

P. 222, line 2 from below, eq. (5—181) exactly corresponds to the Rayleigh reflection coefficient for reflection from a 1—3 interface, contrary to the statement in the text.

P. 223, eq. (5—182), read ω instead of w in all three expressions.

P. 224, line 10 from above, read (5—186) instead of (5—184).

P. 227, line 16 from below, read $V = c_1/\sin \theta$ instead of $V = \sin \theta / c_1$.

P. 231, line 4 from below, read Eq. (5—196) instead of Eq. (5—194).

P. 252, eq. (6—9), expression for m_1, read ν instead of v.

P. 254, eq. (6—19), first line, read s_V instead of c_V.

P. 266, eq. (6—83), read $-k_1 x$ instead of — $k_1 x$ in exponent, as the wave is assumed to propagate in the negative x-direction.

P. 267, eq. (6—84), two last equations, read ω^2 instead of w^2.

P. 276, eq. (6—121) and eq. (6—122), read Intensity $\sim$ (proportional to) instead of Intensity α.

It is our hope that the misprints etc. will be corrected in a second edition of the book. Another wish for the second edition is that all numerical information should also be given in the metric system. An information that sound velocity increases with temperature at a rate of about 5.7 ft/sec per degree Fahrenheit (p. 19) does not mean much for people educated in the metric system before translation into m sec and degree Centigrade, just to mention one example.

Markus Båth

HUGO FREUND: Handbuch der Mikroskopie in der Technik; Bd. II: Mikroskopie der Bodenschätze; Teil 3: Mikroskopie in der Geologie sedimentärer Lagerstätten (Mikropaläontologie). Umschau Verlag, Frankfurt am Main 1958. Pris DM 115:—.

Denna volym om 450 sidor text och 30 sidor sak- och författarregister representerar ett enhetligt verk trots att olika författare behandla skiftande områden. De allmänna kapitlen om mikropaleontologiens historia och paleontologiens användning i geologien, särskilt inom oljegeologien, är skriven av H. Hiltermann. Bägge kapitlen är ganska knappa men lämna precis den översikt, som är nödvändig inom hela det stora arbetsområdet. I sådana fall där dessa kapitel, särskilt det andra, behandla en eller annan metod relativt knapphändigt, så finnas flera och detaljerade uppgifter i de övriga delarna av boken. Ändå skulle man gärna ha sett några ord om fasmikroskopiens användningsområden, och elektronmikroskopien. Särskilt saknade anmälaren slipprovens betydelse och deras moderna teknik.

H. Bartensteins bidrag om mikropaleontologiens betydelse inom oljegeologien behandlar utnyttjandet av paleontologiska resultat för lösning av stratigrafiska, tektoniska och paleogeografiska problem. Man önskar, att dessa 18 sidor skall läsas icke bara av geologistuderande utan även av stora grupper paleontologer och mikropaleontologer, som sällan bry sig om de geologiska problemen.

E. Triebel har med hela sin långa erfarenhet lämnat sitt bidrag om fotografien. Alla som känna till Triebels egna arbeten och hans illustrationer välkomna hans uttömmande beskrivning om fotografering av »stora» mikroobjekt, d. v. s. den kritiska fotograferingen av mindre förstoringar mellan 5 och 100 ggr. Som gammal praktiker önskar anmälaren framhäva, att de av Triebel lämnade textillustrationerna tala sitt eget språk om fotograferingens möjligheter och kontrastera mot det mesta man har sett under de sista 10 årens publikationsverksamhet inom »Mikropaleontologien»! Ändå saknade anmälaren även här några hänvisningar till slipsnittfotograferingen, som kommer att spela en större roll t. o. m. inom Dr Triebels speciella arbetsområden.

Dr H. Beckmann behandlar den del av mikropaleontologien, som borde ha en särskild betydelse för våra skandinaviska paleozoiska bergarter (Arbeitstechniken und Erfahrungen der Mikropaleontologie im Paläozoikum). Tyvärr är kapitlet mycket kort och summariskt, och författarens påstående att den mikropaleontologiska forskningen i paleozoikum fortfarande står i sin början måste väl anses som mycket lokalpatriotiskt. Författaren har glömt det stora arbetsområdet inom karbon och perm med fusuliner, konodonter, ostracoder och andra paleozoiska mikrofossil. Arbetstekniken av Schwartz (1931), som omfattar inte bara preparering utan också en mästerlig fotografering, skulle ha behandlats på ett mycket utförligare sätt, i proportion till de därvid vunna resultaten. Kritikern anser sig även skyldig påtala, att de till detta kapitel bifogade illustrationerna knappast motsvara de av Triebel i föregående kapitel angivna råden. Ändå ger även denna del en översikt över ämnet, som räcker till för att man med hjälp av citerad litteratur skall kunna specialisera sig i ämnet.

Med behandlingen av foraminiferer beträder Hilterman de speciella arbetsområdena. Alla taxonomiska frågor har Hilterman reducerat till den principiella karaktären och lämnar en kortfattad klassifikationstabell, som väl räcker till i detta sammanhang. Stratigrafiskt observerade ändringar inom en särskild grupp av ett genus har Hilterman flera gånger tidigare behandlat och ger i denna bok exempel på sådana undersökningsmetoder och deras betydelse. Kapitlet saknar inte originalitet och egenvärde för arbetsmetodiken med foraminiferer, men omnämner varken direkt eller i litteraturförteckningen hela arbetsområdet. Man saknar hänvisning till Bartensteins och Brands klassiska behandlingar av foraminiferfaunans förändringar inom nordtyska lias liksom hela de stora arbetsområdena om storforaminiferer genom paleozoikum, mesozoikum och kaenozoikum. Mest besviken är anmälaren över avsaknaden av hela arbetsmetodiken beträffande foraminiferernas fortplantning (generationsväxlingar och formstatistik). Kanske att utrymmet, som stod författaren till förfogande, ej räckte till att behandla dessa arbetsmetoder, medan andra metoder i utmärkt form framställts för läsaren.

Den andra delen av redogörelserna för speciell arbetsmetodik behandlar ostracoder och författaren, Dr E. Triebel, nämner redan i början, att han inskränker sig till huvudsakligen mesozoiska och neozoiska formgrupper. Hela problemområdet blir översiktligt framställt såväl beträffande undersökningstekniken som de ekologiska förhållandena, djurkroppen och skalen, samt skalens morfologi. Författaren behandlar med hänsyn till paleontologens material skalens morfologi mycket utförligare än handbokens uppläggning låter förmoda, så att icke-specialisten endast är tacksam för denna form av introduktion. De avslutande avsnitten över fortplantning, larvutveckling, parasiter och klassifikation är knappa men uttömmande. Illustrationer och text motsvarar det stora vetande och den betydande erfarenhet, över vilka författaren förfogar.

I kapitel 3 ger Dr H. Sieverts-Doreck en översikt av echinodermrester som mikrofossil. Författaren riktar uppmärksamheten på vilken roll echinodermrester såväl kvantitativt som kvalitativt spela i sedimenten. Siffrorna över antalet av element för vissa former av asteroider och crinoider (48 000 armdelar hos Thenarocrinus callipygus ur Gotlands silur och 5 millioner segment av Seirocrinus från Tysklands lias) ger tillräckliga bevis för betydelsen av dessa mikrofossil! Hela det korta kapitlet ger en utmärkt handledning för behandlingen av echinodermdelar i sediment. De nästan notisartade hänvisningarna för de olika grupperna räcker till som inledning och stimulans att fortsätta inom detta arbetsområde, och därtill räcker även de tämligen råa teckningarna på de bifogade sex planscherna. När Quenstedt 1874—76 och Brünnich-Nielsen 1913 nämnas ur litteraturen, så borde något mera än bara ett arbete av Frizzell och Exline och speciellt den i texten nämnde Wienberg-Rasmussen ha blivit uppräknade.

W. Weiler nämner i en lika kort översikt fiskrester, särskilt ooliter. Utöver en god orientering över ooliternas taxonomiska och morfologiska behandling ger uppsatsen knappast mera. Hela den mikropaleontologiska betydelsen av ben, fjäll och tänder av fiskar och agnater har fallit bort, och anmälaren önskar särskilt i detta samband påpeka, att för geologiska, sedimentologiska och stratigrafiska problem fisk och agnatrester spelar en större roll än ooliter. Därför kan man i en tysk handbok i detta ämne knappast negligera de tyska arbetena av W. Gross och E. Aldinger, helt bortsett från de talrika utomtyska publikationerna.

Den återstående delen av boken upptar arbetsområden inom paleobotaniken med K. Mädler: Charaophyter, U. Rein: Pollenanalys av tertiära brunkol, samt F. Overbech: Pollenanalys av kvartära bildningar. (Att i detta avsnitt undersökningen av honung behandlas, tycks något konstigt.) Vidare ingå: R. Potonié: Förutsättningar för en sporstratigrafi av stenkolslagren, och F. Hustedt: Preparation av och undersökningsmetoder för fossila diamotéer. Anmälaren är knappast specialist inom nämnda områden och kan endast se alla dessa arbeten från den praktiskt arbetande geologens synvinkel. Från en sådan synpunkt ger alla arbetena en bra handledning över ifrågakommande teknik och arbetsmetodik. Ett undantag bildar Overbecks pollenanalys och kvartära bildningar, som är mycket utförligare än en handledning. Särskilt den icke-taxonomiska behandling han så utmärkt använder som introduktion till arbetsmetoderna verkar ganska allsidig. Den taxonomiska delen däremot räcker inte för vetenskapligt arbete och är för utförlig för en orientering. En starkare betonad hänvisning till Faegri och Iversen eller till Erdtmanns grundläggande arbeten skulle väl vara mera på sin plats. Ändå är litteraturförteckningen förhållandevis utförlig, och omnämnandet av de periodiska litteraturförteckningarna av Erdtmann, Gams och Sears räcker för alla dem, som skall sätta sig in i detta högspecialiserade område av den moderna kvartärgeologien.

Anmälaren har själv fått det intrycket, att han behandlat denna del av handboken för långrandigt. Men en så allsidig översikt över ämnet mikropaleontologins metodik har hittills saknats, om man bortser från M. F. Glässners (1945) mästerliga försök: Principles of Micropaleontology. Glässners bok är tyvärr ute ur handeln och ersättare saknas. Mikroskopie in der Geologie sedimentärer Lagerstätten är i praktiken en fortsättning av Glässners Principles, och ett stort steg framåt. Medan Glässner försökte (se referat i G. F. F., Bd 69) att ensam belysa mycket olika områden inom ämnet, så har här specialister behandlat sina specialområden. Det mest värdefulla i hela boken är att enhetligheten inte har blivit lidande genom detta förfarande. Bortser man från de få kritiska anmärkningarna över de enstaka delarna, så saknas ett mycket viktigt område, som i form av ett litet appendix skulle väsentligt ha kompletterat boken, nämligen mikrofotografi av sediment med tonvikt på fossil, d. v. s. den del av mikropaleontologien, som Cuvillier kallade mikrofacies.

Anmälaren önskar rekommendera boken, både för den arbetande stratigrafen och paleontologen såsom handbok för orientering, och för den studerande såsom en allsidig översikt över ett viktigt praktiskt och vetenskapligt arbetsområde.

F. Brotzen

Vladimír Pokorný: Grundzüge der zoologischen Micropaläontologie, Band I. V. E. B. Deutscher Verlag der Wissenschaften, Berlin 1958. Pris RM 48.

Föreliggande skrift är tänkt som lärobok för högskolestuderande och som ett uppslagsverk för mikropaleontologer i praxis. I dag har redan flera universitet och högskolor i utlandet en regelbunden undervisning i »mikropaleontologi» och nästan alla geologer, som i sedimentområden arbetar med stratigrafiska eller praktiska problem, har på något sätt blivit tvungna att arbeta med så kallade »mikrofossil».

Det är inte möjligt att i detta samband nagelfara begreppet »mikrofossil» och »mikropaleontologi». Man är trots flera inlägg och betänkanden tvungen att acceptera ett arbetsområde med dess terminologi, så som det uppkommit ur en nu trettioårig praxis. Under de sista åren har framkommit några mer eller mindre korta läroböcker i ämnet, av vilka endast tre ha betydelse, nämligen Cushman: Foraminifera (1948), Galloway: A manual of foraminifera (1953) och Glässner: Principles of micropaleontology (1948).

I motsats till det sist nämnda verket är det nya redan genom titeln koncentrerat till fossila djur eller djurdelar. Därigenom har verket vunnit betydligt. Upprepningar och missförstånd, som annars lätt uppkomma, ha på så sätt kunnat undvikas. De tre inledande kapitlen om mikropaleontologien och mikrostratigrafien (enligt undertecknad en beteckning som så fort som möjligt bör försvinna), insamling, preparation, undersökning av mikrofossil och slutligen mikrostratigrafiska metoder är sammanpressade på 51 sidor. Resten av boken, sid. 52—468, utgörs av den speciella delen med radiolarier, thekamöbor, foraminiferer, tintinniner, incertae sedis, chitinozoa, hystrichosfärer och liknande mikroorganismer, varefter en diger litteratur, sak- och författarförteckning följer (sid. 469—572). Som i Glässners verk dominera även i detta band foraminiferer med särskild tonvikt på deras taxonomi (340 sid.). Detta innebär inte, att författaren har behandlat de övriga djurgrupper otillräckligt. Tvärtom ger dessa kapitel en bra och lättillgänglig översikt. Dessa översikter kan ofta för vissa grupper vara ganska korta, såsom beträffande thekamöbor, tintinniner o. s. v., men å andra sidan är kapitlet över radiolarier omfångsrikare och mer detaljerat. Trots detta borde en bok med zoologisk inriktning vid behandlingen av såväl radiolarier som foraminiferer mera utförligt ingå på levande formers byggnadssätt och på deras förökning än vad som nu är fallet. Fler figurer till belysning av processerna vid generationsväxling borde visas. Den invecklade mekanismen vid sådana processer kunde göras klarare, om de avbildningar, som givits av Calvez eller Myers, hade återgivits. En stor del av taxonomisk problematik skulle i så fall bli lättare att förstå och en hel del onödig diskussion kunde bortfalla. Hela kapitlet om radiolariernas ekologi saknar hänvisningar till moderna oceanografiska arbeten, vilka även saknas i litteraturförteckningen.

Redan i de inledande kapitlen, och ännu mera i de speciella, framträder en av de positiva och mest värdefulla linjerna i hela boken, nämligen att Pokorny visar sig vara den första författaren inom mikropaleontologien, som behärskar litteraturen från båda de politiskt så skarpt och olyckligt skilda områdena Öst och Väst. Mest markant framträder denna stora tillgång i foraminiferkapitlen. En sådan framställning har hittills saknats, och den gör boken värdefull för de bredaste kretsar. Den taxonomiska delen av foraminiferakapitlet är mycket utförlig, men man undrar varför vissa genera är medtagna och andra inte. Det ligger i bokens karaktär, att ett urval måste göras — men ofta har det skett med en polemik eller med ett refererande av pågående diskussioner, som skjuter långt över målet.

I avsnittet om den taxonomiska indelningen har författaren försökt att bygga in undersökningar av den palaeozoiska faunan i hela systemet så långt detta varit möjligt, något, som är ett nytt steg framåt och som har lett till resultat överlägsna flera nu föreliggande sammanfattningar. Helt lyckad är den taxonomiska indelningen dock inte, och det ser ut som om en del av den nya uppordningen av superfamiljer och familjer gör det svårare för studerande och icke-specialister att nå ett allmänt grepp på ämnet.

Men i stort sett finns det bara en anmärkning mot denna så värdefulla och givande bok, nämligen illustrationerna. Boken är rikligt illustrerad och de 549 illustrationerna kunna vara mer än tillräckliga. Nästan alla är utmärkt valda, men förenklingarna och omritningarna lämna ofta oklara och mindervärdiga framställningar. Trycket i fotografierna är genomgående flackt och uttryckslöst, vilket gör, att man knappt känner igen de välkända originalen. Sämst är omritningsförfarandet, när någon form har blivit avbildad genom sekundär omritning: »nach Möller, aus Cushman, umgezeichnet», eller: »nach Brady aus Cushman, umgezeichnet». Det är ett lönande arbete att jämföra bilderna i Brady (1884) med dem i Pokorny (1958), till exempel fig. 332 och 411.

Denna anmärkning, hur viktig den än må vara, och även anmälarens personliga, avvikande uppfattning i enstaka frågor, förminska icke det värde som boken har. Den är en stor tillgång, ett framsteg inom arbetsområdet och kan varmt rekommenderas.

F. Brotzen

PIERRE LAFITTE: Introduction a l'étude des roches métamorphiques et des gîtes métallifères. Physico-chimie et termodynamique. 106 textfigurer, 39 tabeller, XVI + 275 sidor. Masson et C^ie^, Paris 1957. 4,000 frs.

Lafitte's bok har fått en något missvisande titel, då man får den uppfattningen att det rör sig om en elementär lärobok om de metamorfa bergarterna. Så är dock ingalunda fallet. Innehållet visar sig vara en osedvanligt fullständig redogörelse för de kemiska och fysikalisk-kemiska förhållanden, vilka utgöra grunden för metamorfosläran. Boken har indelats i fyra delar: Généralités physico-chimiques (65 s.), Composition chimique des roches (75 s.), Thermodynamique (115 s.) och Pétrologie des roches métamorphiques (80 s.). Någon bergartslära i egentlig mening är ej medtagen i det sista avsnittet, utan där ha de kunskaper läsaren fått i de tre föregående avsnitten tillämpats på de olika petrologiska spörsmålen. Några underrubriker från detta avsnitt får tjäna som exempel: Métamorphisme et Energie, Le temps dans le métamorphisme, La différenciation métamorphique, Origine des apports métasomatiques, Cycle de l'eau, etc.

Lafitte's bok liknar ej de vanliga, oftast engelskspråkiga metamorfosläroböckerna. Den är snarast upplagd som en lärobok i metamorfoslärans grundvetenskaper. Den förutsätter ej alltför ingående förkunskaper, men går ändå in på de olika problemen i detalj. Uppläggningen är mycket pedagogisk, i de flesta avsnitten förekomma rikligt med konkreta exempel.

Det är alltid av stort intresse att studera en lärobok, som är upplagd på ett nytt sätt. Det är svårt att utvälja något speciellt ur denna välskrivna bok, det skulle möjligen vara en så ovanlig sak som en utredning över reaktionsmekanismen i intergranularen. Om man skulle önska något beträffande Lafitte's metamorfoslära, så vore det att den måtte utkomma i en engelspråkig upplaga för att nå en större spridning även utanför de franskspråkiga områdena.

Pontus Ljunggren

JEAN JUNG: Précis de pétrographie. Roches sédimentaires, métamorphiques et éruptives. 160 textfigurer och 20 planscher, 314 sidor. Masson et C^{ie}, Paris 1958.

Förlaget Masson et C^{ie} har under de senaste åren utgivit ett flertal franskspråkiga läroböcker behandlande skilda delar den geologiska ämnesgruppen. Senaste tillskottet är professor Jung's lärobok i petrografi. Bokens indelning är den normala för petrografier: mineralogi 40 s., sedimentära bergarter 90 s., metamorfa bergarter 60 s. och eruptivbergarter 100 s. Att det mineralogiska avsnittet ej gör anspråk på någon fullständighet är ju på grund av sidantalet fullt klart, men det kan med fog sägas att den mineralbeskrivning som här gives är osedvanligt ofullständig. Av boktiteln framgår, att förf. icke eftersträvat att framlägga petrologiska synpunkter utan velat giva en rent deskriptiv bergartsystematik. För närvarande undergår ju petrografien en omklassificering i det att den metamorfa avdelningen växer huvudsakligen på eruptivbergarternas bekostnad. Beträffande speciellt de metamorfa bergarterna kan anmärkas, att J. Jung har delat upp de bergarter som icke förts till sedimentära eller eruptiva avdelningarna på två huvudgrupper: mekaniskt deformerade resp. metamorfa, och han motiverar detta med att endast intensivt omkristalliserade bergarter böra föras till huvudgruppen metamorfa bergarter. Lämpligheten av att på detta sätt särställa de dynamometamorfa bergarterna är diskutabel.

Illustrationerna utgöras av 160 tecknade figurer och 40 fotografiska reproduktioner, varav åtminstone en del av teckningarna äro av tvivelaktigt illustrationsvärde (kvadrat innehållande parallella svarta streck = trådig gips!). Själva texten och uppläggningen i övrigt motsvarar ungefär vad som fordras för högre betyg i svensk fil. kand.-examen.

Pontus Ljunggren

Mötet den 15 januari 1959

Närvarande 68 personer.

Ordförande hr O. Meier öppnade sammanträdet med följande anförande.

Den 30 juni 1958 avled bergsingenjör E. W. Stollenwerk, Askersund, i en ålder av 81 år.

Han var född i Hammar i Örebro län den 3 juni 1877 och avlade mogenhetsexamen 1897. Han studerade därefter vid Kungl. Tekniska Högskolan och utexaminerades därifrån 1905. Från sistnämnda år och fram till pensionsåldern var han anställd vid Bolaget Vielle Montagnes avdelning i Sverige. Stollenwerk var konsult i anrikningsfrågor inom detta världsomfattande företag. — Vår Förening tillhörde han sedan år 1903.

Den 8 december 1958 avled ingenjör Nils Rosén, Stockholm, i en ålder av 64 år.

Han var född i Folkärna i Dalarne den 17 oktober 1894. Efter examen vid Bergsskolan i Falun 1917 och några kortare anställningar var han ingenjör åren 1923—25 vid Fosdalens Bergverk A S i Norge. Åren 1926—35 var han 1:e gruvingenjör vid Bolidens Gruv AB. Därefter blev han chef för gruvprospekteringen vid O/Y Atvi i norra Finland. Vår Förening tillhörde han sedan år 1941.

Jag lyser frid över de bortgångnas minne.

Till ledamöter av Föreningen har styrelsen invalt

preparator Bengt Wigström, Stockholm, geologbiträdet Rune Aldehag, Stockholm, och geologbiträdet Gottfrid Westerberg, Stockholm, föreslagna av hrr P. H. Lundegårdh och Th. Lundqvist,

vidare dr. phil. Peter Padget, Stockholm, föreslagen av hrr T. Eriksson och E. Åhman

samt

överingenjör Tell Justus Osterman, Stockholm, tekn. lic. Sven Hansbo, Stockholm, Dr. ing. Werner Bergau, Stockholm, ingenjör Lyman Cadling, Stockholm, och civilingenjör Torsten Kallstenius, Stockholm, föreslagna av hrr O. Meier och B. Johansson,

vidare envoyè Arne Lundberg, Stockholm, direktör Olle Berggren, Stockholm, och direktör Erik Johnsson, Stockholm, föreslagna av hrr O. Meier och K. G. Wallin,

överingenjör Sven Erik Sjöberg, Falun, direktör Karl Ingvaldsen, Trondheim, statsgeolog Thor Siggerud, Oslo, tekn. dr Herman Stigzelius, Helsingfors, civilingenjör G. K. Frölich Hansen, Roskilde, fil. mag. Heikki Wennervirta, Helsingfors, Afd.geolog Jan Bondam, Köpenhamn, och lektor Henning Sørensen, Köpenhamn, föreslagna av hr O. Meier,

vidare docent Valter Schytt, Stockholm, föreslagna av herr J. De Geer och E. Åhman samt dr. J. C. Overweel, Leiden, föreslagen av hrr E. Åhman och P. H. Lundegårdh.

Professor A. A. Bogdanoff, Moskva, har per brev framfört sitt tack för valet till korresponderande ledamot av vår Förening.

På grund av ökade tryckningskostnader för Förhandlingarna har styrelsen sett sig nödsakad att komma med ett förslag till en 25 %-ig höjning av medlemsavgifterna att träda i kraft från och med år 1960. — § 7 av våra stadgar föreslås erhålla följande lydelse:

§ 7

Varje ledamot erlägger en årsavgift av tjugofem kronor, vilken avgift senast den 1 mars bör till Föreningens skattmästare inbetalas. Korresponderande ledamot är från avgift befriad.

Ledamot, som på en gång erlägger 300 kronor, är därigenom berättigad att utan vidare erläggande av årsavgiften kvarstå såsom Föreningens ständige ledamot. Ledamot, som under en följd av minst 20 år erlagt årlig ledamotsavgift, kan bliva ständig ledamot mot en avgift av 150 kronor. Ledamot, som under en följd av 50 år erlagt årlig ledamotsavgift, blir ständig ledamot utan särskild avgift. Ständiga ledamöters avgifter skola ingå till Föreningens reservfond, — — —

På grund av omläggning av häftenas distribution komma dessa tyvärr ej längre att utdelas vid sammanträdena utan i stället per post tillställas samtliga medlemmar.

Ordet överlämnades efter dessa meddelanden till docent Valter Schytt, Stockholm, vilken höll ett med talrika färgbilder och kartor rikt illustrerat föredrag med titeln; Några synpunkter på recenta landisar.

En uppsats i ämnet kommer att införas i ett kommande häfte av Förhandlingarna. — I anledning av föredraget yttrade sig fru Ebba Hult De Geer samt hrr F. Brotzen, Fellenius, Hoppe, Wenner och föredragshållaren.

Fru Ebba H. De Geer ansåg de givna exemplen från nutida landisar av största värde för uppfattningen av forna landisar. Så gäller t. ex. ifråga om firnens stora djup och förhållande till temperaturen. Betydelsefull är också en säker kännedom om att den kvartära nedisningen vid något maximistadium utbrett sig över Barents havs kontinentalsockel — vilket väl motsvaras av att landisen under Würmtiden kunnat framskrida över den ännu flackare Nordsjöns botten, såsom framgår av professor Valentins kartkonstruktion med en isdämd sjö i Nordsjöns norra del. Därmed stämmer även prof. H. Holtedahls resultat, att den norska kusten under Würmtiden varit täckt av en synnerligen mäktig is, som nått ända till 40 kilometer ut över kontinentalsockeln och som föga medgivit plats och klimat för refugier, åtminstone icke förr än i Bölling- och Allerödinterstadialerna.

Vid mötet utdelades nr 495 av Förhandlingarna.

Geolognytt

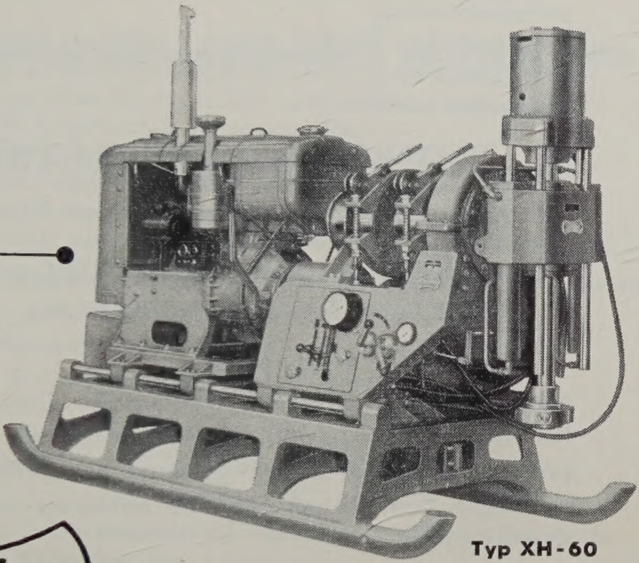
På första dagen av Kungl. Vattenfallsstyrelsens femtioårsjubileum den 20 januari 1958 frambars Sveriges geologiska undersöknings lyckönskan av överdir. K. A. Lindbergson samt doc. G. Ekström och statsgeolog W. Larsson.

Vid Sveriges geologiska undersökning har inrättats en publiceringsnämnd bestående av
prof. G. Lundqvist (ordf.),
doc. P. H. Lundegårdh,
statsgeolog E. Mohrén samt
geolog G. Bexell.

Till geolog vid Grängesbergsbolaget med placering i Grängesberg har utsetts fil. lic. H. W. Lindholm, Uppsala.

Till chefsgeolog vid Johnsonkoncernen har fr.o.m. 1 mars 1959 utsetts statsgeologen fil. lic. Tryggve Eriksson. Denne åtnjuter tjänstledighet från sin statsgeologbefattning till årets slut.

Fil. lic. Hans Sarap åtnjuter tjänstledighet från sin geologbefattning vid Sveriges geologiska undersökning till utgången av år 1959 för tjänstgöring som F.N.-expert i Jordanien.



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Pris för detta häfte: 11 kronor

STOCKHOLM 1959. KUNGL. BOKTRYCKERIET P. A. NORSTEDT & SÖNER